Channel Modeling of Underwater Wireless Sensor Network using EM Waves

[1]Gursewak Singh, [2]Mahendra Kumar
[1]Research scholar, Guru Kashi University, Talwandi Sabo, Punjab, India,
[2]Dy. Dean Research, Guru Kashi University, Talwandi Sabo, Punjab, India

Abstract: In this paper, the practical feasibility and applicability of Electromagnetic (EM) waves in water medium was examined after performing simulation process through theoretical and mathematical tools. The analysis of EM waves was performed through some significant factors such as Path loss (*pl*), Signal to noise ratio (SNR), Bit error rate (BER). It was observed that the EM waves have more feasibility in fresh water as compared to sea water. A case study was presented that employ electromagnetism effect of EM waves in underwater wireless sensor network. The results obtained demonstrate the likely effectiveness of the designated under water architecture.

Index terms- **EM waves, Water medium, Signal to noise, Bit error rate, Path loss, Transmission power**

1 INTRODUCTION

As by researcher in [1], the propagation of electromagnetic (EM) waves in a medium with non-zero conductivity was elaborated, examining the dielectric characteristics of the sea water, in order to analyze a wireless communication channel model. Mathematical models for sea water wavelength, dielectric constant, path loss were presented when an electromagnetic wave (EM) at 2.4GHz pass through sea water. As by researcher in [2] had shown great interest to the industry and military, it plays an important role in pollution monitoring, tactical surveillance, and maintenance, monitoring of climate change, and research of oceanography. In order to handle all these activities, number of unmanned vehicles or devices was deployed in underwater to obtain high bandwidth and high capacity for information transfer in underwater medium [2]. As in [3], author used real measurements of the under-water channel to simulate whole underwater radio frequency (RF) wireless networks, including impairments in propagation (e.g., interferences, noise), EM radio hardware (e.g., bandwidth, modulation scheme, power transmission). As in [4] , the researcher analyzed the propagation based on EM waves in the 315/433 MHz band through a solid: soil, coal, oil sand, and liquids: water, salty water, and crude oil medium in order to explore its applicability. As in [5], the researcher evaluated several EM wave-based three-dimensional (3D) UWSN architectures differing in topologies and/or operation principles on the performance of localization and target tracking. As in [6], the author presented a comprehensive survey of underwater optical wireless networks (UOWNs) research. This survey covers different aspects of cutting-edge UOWNs from a layer by layer perspective. As in [7], researcher presented the characteristics of EM waves wireless communication sensor network in shallow water medium with variation of salinity.

2 RELATED WORK

2.1 The Propagation of EM waves in water medium

Consider linear homogeneous, water medium. Sea Water is conducting medium and imperfect medium while fresh water is non conducting medium. As, waves propagate through water medium, propagation constant (ρ_c) term [8-10] is obtained which depends upon the phase constant (ϕ_β) of signal and attenuation constant (ϕ_α) of signal in water medium as shown in equation (1).

$$\rho_c = \left(\phi_\alpha + \hat{j}\phi_\beta\right) = \left(\hat{j}\cdot\omega\cdot\mu_{mp}\cdot\left\{\left(\square_c + \hat{j}\cdot\omega\cdot\varepsilon_{mp}\right)\right\}\right)^{\frac{1}{2}} \tag{1}$$

Where, as in [8-10]

$\square_c = 4(\text{mho}/meter)$, $\omega = 2\pi\cdot\zeta_{freq}$ $\mu_{mp} = \mu_0\cdot\mu_{mr} = 4\pi\cdot10^{-7}(Henry/meter)$, $\omega = \left(2\cdot\pi\cdot\zeta_{freq}\right)$ is angular frequency. (ζ_{freq}) is frequency of signal and ε_{mp} is permittivity of medium, $\varepsilon_{mp} = 8.85\cdot10^{-12}(F/m)$ is permittivity of medium, μ_p is permeability of water medium, $\square_c$ is conductivity of medium, $\mu_{mr} = 1$ is relativity permeability [9-10].

$\mu_{mp} = \mu_0 = 4\pi\cdot10^{-7}$ is permeability of free space same as in water medium [8-10].

Expression $\left\{\frac{\square_c}{\omega\cdot\varepsilon_{mp}}\right\} >> 1$ [8-10] can be placed in equation (2) written below for conductive medium to obtain equation.

$$\rho_c = \left(\phi_\alpha + \hat{j}\,\phi_\beta\right) = \left(\omega^2 \cdot \mu_{mp} \cdot \varepsilon_{mp}\left\{\left(\hat{j}\,\frac{\square_c}{\omega\cdot\varepsilon_{mp}}\right) - 1\right\}\right)^{\frac{1}{2}} \tag{2}$$

$$\rho_c = \left(\phi_\alpha + \hat{j}\,\phi_\beta\right) = \left(\omega^2 \cdot \mu_{mp} \cdot \varepsilon_{mp}\left(\hat{j}\,\frac{\square_c}{\omega\cdot\varepsilon_{mp}}\right)\right)^{\frac{1}{2}} \tag{3}$$

At frequency below 800MHz as from consideration in [7-10] and equation (1, 3), After separating real and imaginary part of equation (3), attenuation and phase constant in form of equation (4) was obtained.

$$\phi_\alpha \approx \square\, \phi_\beta = \left(\frac{\phi_{freq}\cdot\mu_{mp}\cdot\square_c}{2}\right)^{1/2} = \left(\frac{\phi_{freq}\cdot 4\pi\cdot 10^{-7}\cdot\square_c}{2}\right)^{1/2} \tag{4}$$

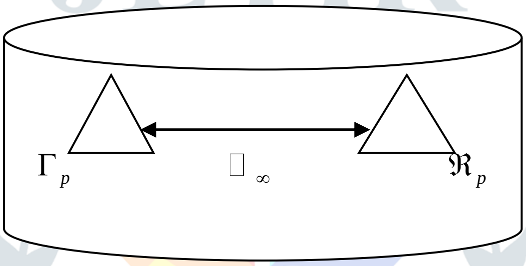

Figure 1 Channel modeling architecture in water medium

As shown in figure (1), transmitter side, suppose a signal is transmitted by power Γ_p is affected by noise power p_n. Total Path loss (*pl*) can be defined as by the difference between Transmitted (Γ_p) and received signal ($\Re_p$)

Where;

$\square_\infty$ is communication range or distance between wireless sensor at transmitter side and wireless sensor at receiver side.

Total path Loss (*pl*) in equation (9) can be determined from Friis equation (5) [8-10].The received power ($\Re_p$) depends upon the transmitted power (Γ_p), received signal power ($\Re_p$), Transmitter gain (Γ_g) and Receiver gain ($\square_g$). Path loss in air is different from path loss in water medium. So, Path loss in air as per Friss equation can be modified and extended in equation (5) [8-10].

$$\Re_p = \frac{\Gamma_p . \Gamma_g . \square_g}{pl} \tag{5}$$

Total path loss (*pl*) in water medium can be expressed as combination of path loss ($pl_{\beta m}$) due to change phase constant in medium and refractive index of water medium w.r.t air and path loss ($pl_{\alpha m}$)due to attenuation of signal ($\vec{X}(x)$) [8]. The Attenuation Path loss also occurs due to attenuation ($pl_{\alpha m}$) because of which signal amplitude (χ_0) decreases as wave travelled a particular communication range ($\square_\infty$) as in equation (9) [8-10].

$$pl = pl_{\beta m} + pl_{\alpha m} \tag{6}$$

$$pl_{\beta m} = \left(2.\phi_{\beta}.\square_{\infty}\right)^2 \tag{7}$$

Where

pl is total loss in water medium. ($\square_{\infty}$) is communication range, (ϕ_{β}) is phase constant of signal and (ϕ_{α}) is attenuation constant of signal in water medium.

If amplitude ($\in_0$) of EM wave attenuated by the factor $e^{-\phi_{\alpha}.\square_{\infty}}$ in water medium. The Path loss in equation (8) due to attenuation factor is the loss of a wave passing through water medium in certain direction up-to a certain communication range ($\square_{\infty}$), the wave amplitude decreases by a factor $e^{-\phi_{\alpha}.\square_{\infty}}$ [8-10] is

$$pl_{\alpha m} \cong \frac{1}{e^{-2(\phi_{\alpha}\cdot\square_{\infty})}} \tag{8}$$

Total path loss in equation (9) from equation (6-8)

$$PL_{db} = 10\log_{10}\left(\left(2.\phi_{\beta}.\square_{\infty}\right)^2 + \frac{1}{e^{-2(\phi_{\alpha}\cdot\square_{\infty})}}\right) \tag{9}$$

2.2. Signal to Noise (SNR) ratio of EM wave in water medium

Signal to noise ratio (SNR) can be defined as received signal with power $\Re_p$ divided by noise power p_n, given below in equation (10) [10-13]

$$SNR = \Re_p / p_n \tag{10}$$

As, from equation (5), Received power $\Re_p$ Power which will be obtained in equation (11) considering transmitter gain ($\Gamma_g = 1$) and Receiver gain ($\square_g = 1$) [10]

$$\Re_p = \frac{\Gamma_p.1.1}{pl} \tag{11}$$

Normal value of SNR can be written in equation (12)

$$SNR = \left(\Gamma_p / p_n \cdot pl\right) \tag{12}$$

Where

Γ_p is transmitted power in (db. m), p_n is noise power in (db. m)

The SNR of water can be expressed in equation (12) by putting value of total path loss (*pl*) from equation (9) of EM waves in water medium.

2.3. Bit error rate (BER) of EM waves in water medium

The bit error rate (BER) can be defined ad numbers of errors in bits divided by the total number of bits transmitted [8, 13]. Modulation techniques is used in this paper Binary Phase Shift keying (BPSK) [8, 13] which is a two phase modulation techniques where binary bits 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 [8, 13]. Bit Error rate (BER) in equation (13) can be determined after placing the decibel value of SNR from equation (12).

$$BER = \frac{1}{2} erfc(\sqrt{10^{SNR_{dB}}}) \tag{13}$$

3 RESULTS AND DISCUSSION

As, shown in figure (2), for Pure water at salinity=0PPT and fixed Temperature(T) 25(^{0}C), Total Path loss (TPL) is 60.1518(dB), 66.8598(dB), 70.6610(dB), 73.4602(dB), 75.7104(dB) at communication range $\square_{\infty}$ 0.5000(m), 1.5000(m), 2.5000(m), 3.5000(m), 4.5000(m) at different frequency ζ_{freq} value (400(MHz), 500(MHz), 600(MHz),700 (MHz), 800(MHz).

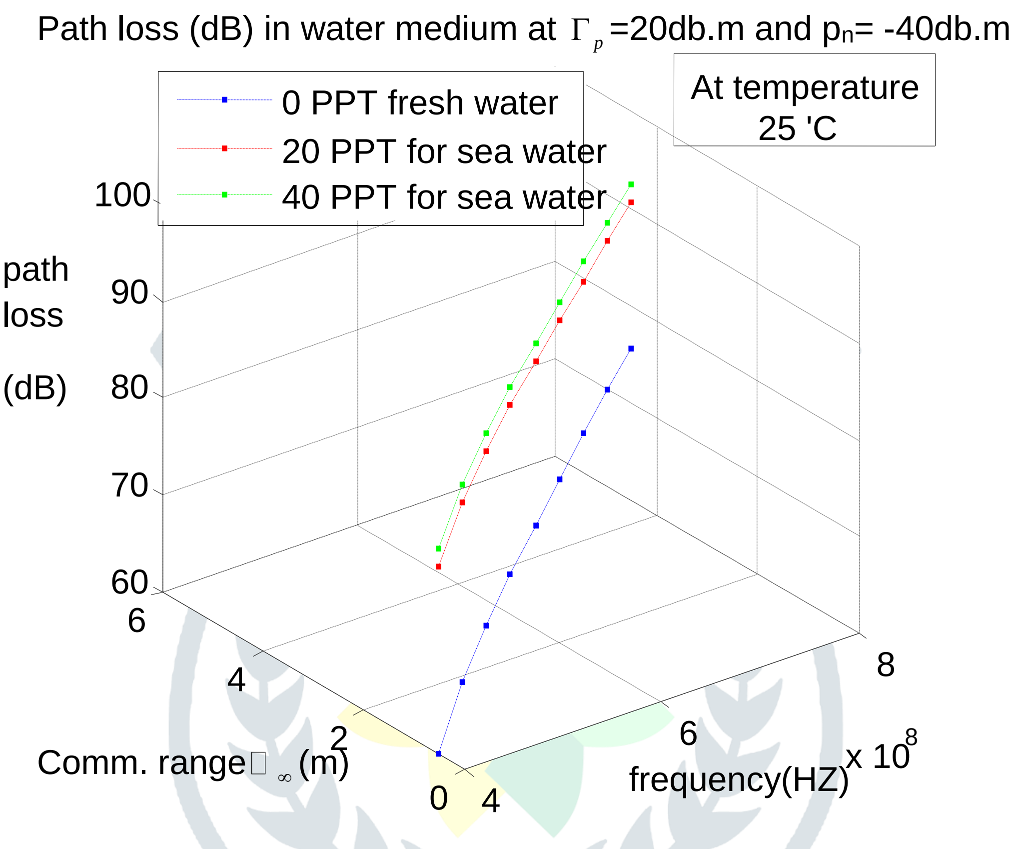

Figure 2 Path Loss variations for sea water and fresh water

In this way, from above observation in figure (2), it can be investigated that Path loss varies according to communication range and frequency range. Path loss of EM waves increases with increase of path distance or communication range. The path loss also increases because of frequency range at fixed temperature. Path loss observed in figure (2) is at transmitted power Γ_p =20 dB. m and noise power level p_n= - 40 dB. m. By increasing salinity factor of sea water, Path loss increases more of EM waves signal in sea water medium.

As shown in figure (2), for sea water at salinity=20 PPT, Total Path loss (*pl*) is 79.4633(dB), 84.7006(dB), 87.3434(dB), 89.2028(dB), 90.6716(dB) at different frequency ζ_{freq} value 400(MHz), 500(MHz), 600(MHz), 700(MHz), 800(MHz) at communication range $\square_{\infty}$ 0.5000(m), 1.5000(m), 2.5000(m), 3.5000(m), 4.5000(m). As, in figure (3, 4), for sea water at salinity=20 PPT and fixed Temperature (T) 25(^{0}C), SNR values are 0.0113, 0.0034, 0.0018, 0.0012, 0.0009 at different frequency ζ_{freq} values (400(MHz), 500(MHz), 600(MHz), 700 (MHz), 800(MHz) at communication range $\square_{\infty}$ is 0.5000(m), 1.5000(m), 2.5000(m), 3.5000(m), 4.5000(m). As shown in figure (3, 4), for Pure water at salinity=0PPT and fixed Temperature(T) 25(^{0}C), SNR is 0.9656, 0.2061, 0.0859, 0.0451, 0.026 at communication range $\square_{\infty}$ 0.5000(m), 1.5000(m), 2.5000(m), 3.5000(m), 4.5000(m) at different frequency ζ_{freq} value (400(MHz), 500(MHz), 600(MHz), 700 (MHz), 800(MHz).

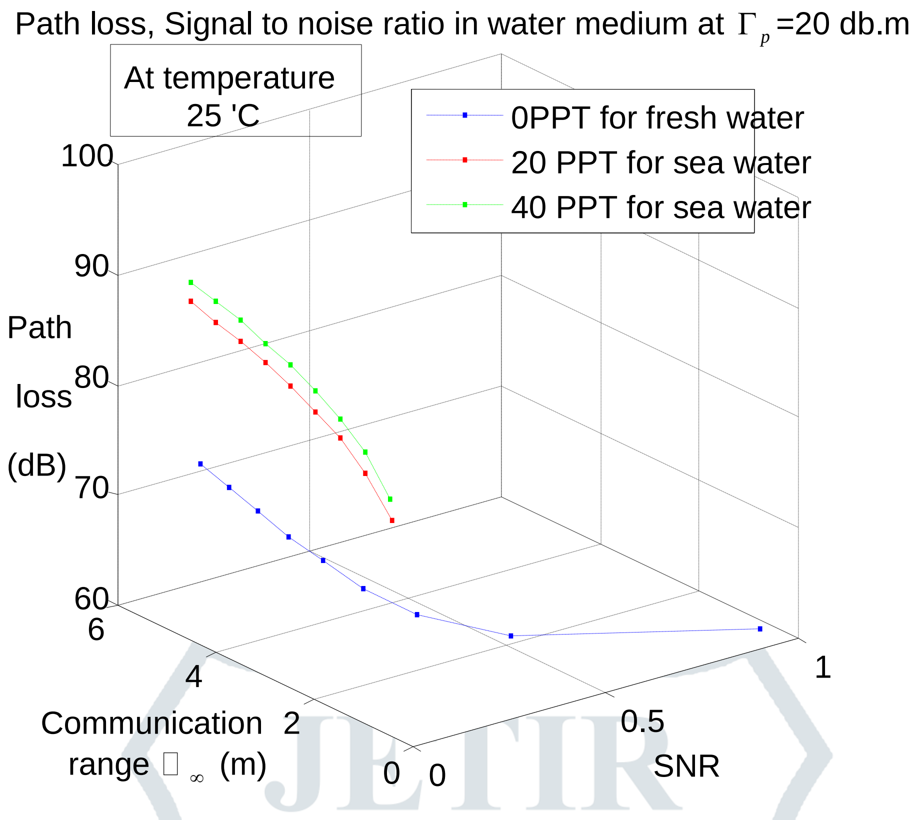

Figure 3 Path Loss and SNR variations for sea water and fresh water

As, shown in figure (4), for sea water at salinity=20 PPT and fixed Temperature (T) 25(^{0}C), BER is 0.4402, 0.4672, 0.4758, 0.4805, 0.4835 at different frequency ζ_{freq} value (400(MHz), 500(MHz), 600(MHz), 700 (MHz), 800(MHz) at □ $_\infty$ =0.5000(m), 1.5000(m), 2.5000(m), 3.5000(m), 4.5000(m).As shown in figure (2), for sea water at salinity=40 PPT and fixed Temperature (T) 25(^{0}C),Total Path loss (*pl*) is 81.2786(dB), 86.5698(dB), 89.2354(dB), 91.0897(dB), 92.5304(dB) at different frequency ζ_{freq} value (400(MHz), 500(MHz), 600(MHz), 700 (MHz), 800(MHz) at communication range □ $_\infty$ =0.5000(m), 1.5000(m), 2.5000(m), 3.5000(m), 4.5000 (m). As shown in figure (4), for Pure water at salinity=0PPT and fixed Temperature (T) 25(^{0}C), BER is 0.0823, 0.2604, 0.3393, 0.3820, 0.4084 at different frequency ζ_{freq} value (400(MHz), 500(MHz), 600(MHz), 700 (MHz), 800(MHz) at communication range □ $_\infty$ =0.5000(m), 1.5000(m), 2.5000(m), 3.5000(m), 4.5000(m).As shown in figure (4), for sea water at salinity=40 PPT and fixed Temperature (T) 25(^{0}C), BER is 0.4514, 0.4735, 0.4805, 0.4843, 0.4867, at different frequency ζ_{freq} value 400(MHz), 500(MHz), 600(MHz), 700 (MHz), 800(MHz) at communication range □ $_\infty$ 0.5000(m), 1.5000(m), 2.5000(m), 3.5000(m),4.5000(m).

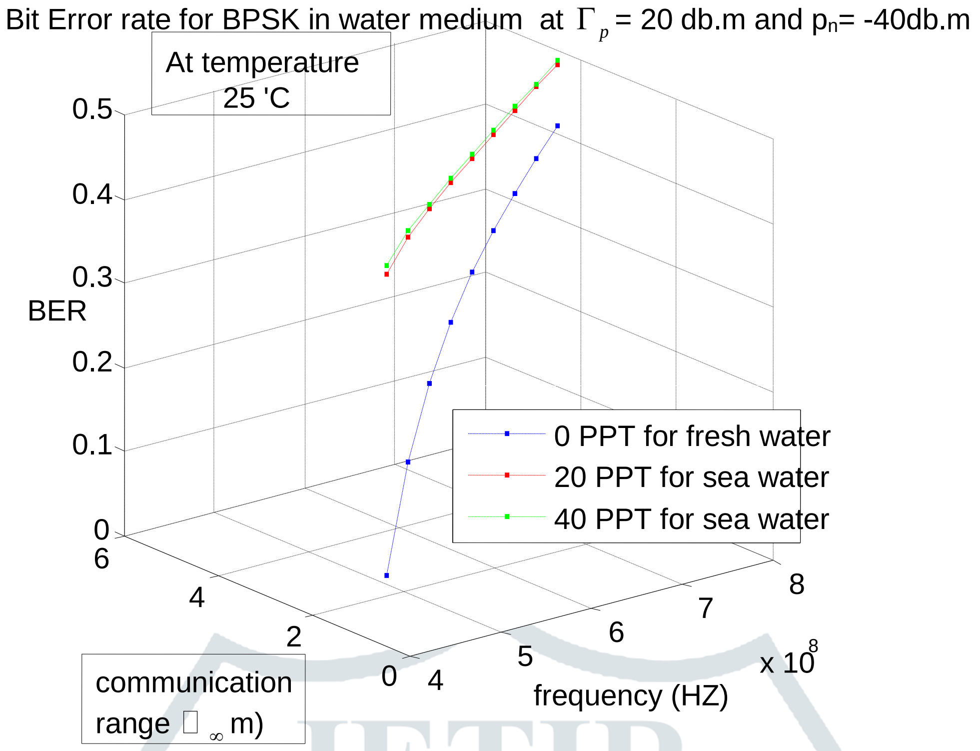

Figure 4 BER variations with communication range for sea water and fresh water.

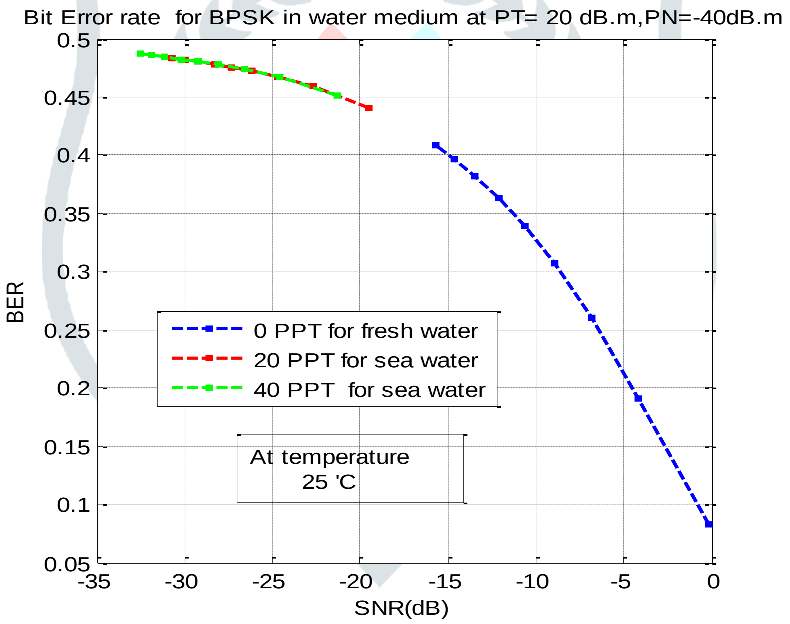

Figure 5 BER variations with SNR for sea water and fresh water

As, from figure (2) and figure (3) and figure (4), It can be observed that SNR decreases and BER, Total path loss (pl) increases with increase of frequency, communication range and variations of salinity=20 PPT and 40 PPT. But on the other side, it can be observed that decrement of SNR, increment of BER, increment of total path loss (pl) increases more with increase of frequency, communication range and variations of salinity for water medium. So EM wave communication is less efficient in sea water as compared to fresh water.

At, end final observation from all result values that High SNR , low BER (bit error rate) can be observed in fresh water as compared to sea water for BPSK (binary phase shift keying) modulation as shown in figure (5). Path loss is also less in fresh water. High signal to noise ratio (SNR) value can be observed for pure water. So EM wave communication is less efficient in sea water as compared to fresh water.

CONCLUSION

In this paper, the performance analysis of Electromagnetic (EM) waves in water medium was examined. However, during examination on EM waves in water medium, some theoretical observations were performed to meet practical specifications for analyzing the applicability of EM waves in water medium. In this paper, the practical applicability of Electromagnetic (EM) waves in water medium was examined after performing simulation process through theoretical and mathematical tools. The analysis of EM waves was performed at frequency range 400MHz-800MHz in sea water medium through some significant factors such as Path loss (*pl*), Signal to noise ratio (SNR), Bit error rate (BER). It was observed that the EM waves have more feasibility in fresh water as compared to sea water. A case study was presented that employ electromagnetism effect of EM waves in underwater wireless sensor network. The results obtained demonstrate the likely effectiveness of the designated under water architecture.

ACKNOWLEDGEMENTS

I would like to thank to Dr. Mahendra Kumar for constant support and encouragement for performing this innovative work.

REFERENCES

[1]A. Evangelia Karagianni, Electromagnetic Waves under Sea: Bow-Tie Antenna Design for Wi-Fi Underwater Communications, Progress In Electromagnetics Research M, Vol. 41, pp.189–198, 2015.

[2] H Kaushal, G. Kaddoum, Underwater Optical Wireless Communication, Multidisciplinary, IEEE Access, vol 4, pp. 1518-1547, 2016.

[3]S. V. Macua, Simulation of Underwater RF Wireless Sensor Networks using Castalia, 2016.

[4]M. A. Akaş, an overview on characteristics of channel for wireless sensor networks, Journal of Engineering and Architecture , Vol. 4, No. 2, pp. 169-183,2016.

[5]K. Munasinghe, M Aseeri, S. Almorqi, EM-Based High Speed Wireless Sensor Networks for Underwater Surveillance and Target Tracking, Hindawi, Journal of Sensors Volume 2017,pp.1-14.

[6]N. Saeed , A. Celik, T.Y. Al-Naffouri, Underwater Optical Wireless Communications, Networking, and Localization: A Survey, IEEE,2018,pp.1-44

[7]S Gursewak, K Mahendra, International Journal of Management, Technology And Engineering ,The characteristics of EM waves wireless communication sensor network in shallow water medium with variation of salinity, Vol IX, Issue I, JANUARY/2019.

[8]G. Stuber, Principles of mobile communication (2/e 2001). Dordrecht: Kluwer (1996).

[9] Arsem Zoksimovki et al., "underwater elecgromagnetic waves using conduction-Channel characteristics", adhoc netwok (2015)

[10]A. Ghasemi.et al, Basic Principles in Radiowave Propagation (springer), (2011)

[11]M. Sadiku, Elements of Electromagnetics, Oxford University Press, NewYork, NY, USA, 2007.

[12] C. E. Shannon, A Mathematical Theory of Communication, Reprinted with corrections from The Bell System Technical Journal, Vol. 27, pp. 379–423, 623–656, July, October, 1948.

[13]T.S Rappaport, Wireless communication: Principle and Practice, Prentice Hall PTR,2002.