LINK BUDGET ANALYSIS FOR UNDEWATER ACOUSTIC SIGNALING

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"To my beloved Father, Mother, brothers, Wife, and Children"

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ABSTRACT

Link-budget analysis is the method to get the link margin of the underwater acoustic communication considering the transmitter signal power, transmitter antenna characteristics, propagation losses, channel ambient noise, and receiver antenna characteristics. Link-budget analysis is commonly applied to satellite and wireless communications for estimating signal-to-noise ratio (SNR) at the receiver. Underwater signal and the terms for the sonar equation translate easily to the formulation of the link budget. However, the high frequency dependence of the diffusion of underwater acoustics requires special attention, and is the result of an argument called signal to noise ratio channel. And compared to many of the problems of communication and voice navigation through link analysis of the large-scale budget. Link budget is applied to voice communications system using the same principles to sea radio link budget. The active sonar equation is utilized to provide an estimate of the first class of signals available at the receiver. Three case studies have shown wireless link budget of the utility systems in the design of broadband communications. Link budget is a useful tool in the perceived impact of the channel on the transmitted signal and evaluate the consequences of the strategic wireless transmission. Aim of this case of the research is design wideband frequency underwater acoustic communication system and comparative study of link budget analysis for underwater communication with the attenuation of the underwater channel by means of the modeling in the MATLAB software. Find out the channel conditions of the underwater acoustic communication in the wideband frequency are strongly range dependent due to underwater attenuation and interference noise. This study found at that link budgeting considers the range and frequency dependence of wideband signals in the acoustic medium. In particular, the channel SNR is strongly frequency dependent in the bands of interest.

ABSTRAK

Dengan mengambil kira kuasa isyarat pemancar, ciri-ciri antena pemancar, rosotan perambatan, hingar ambien laluan, dan ciri-ciri antena penerima, penganalisaan kepada keperluan had-laluan adalah satu kaedah untuk menentukan had keperluan laluan untuk komununikasi akustik di dalam air. Penganalisaan had-laluan sering dilakukan untuk perhubungan satelit dan komunikasi tanpa wayar untuk menentukan nisbah kuasa isyarat kepada kuasa hingar (SNR) pada penerima. Isyarat dalam air dan terma-terma persamaan sonar yang digunakan mudah diterjemahkan kepada formulasi had-laluan. Walaubagaimanapun, resapan akustik di dalam air dengan kebergantungannya kepada ketinggian frekuensi, perlu diberikan perhatian, dan ini adalah hasil daripada perincian tentang nisbah kuasa isyarat kepada kuasa hingar. Juga perbandingan kepada masalah komunikasi dan navigasi suara melalui penganalisaan had-laluan pada skala yang besar. Prinsip had laluan untuk sistem komunikasi suara diaplikasikan kepada had-laluan perhubungan radio di dalam lautan. Persamaan sonar aktif digunakan untuk menganggar isyarat kelas pertama yang tersedia di penerima. Tiga kajian kes telah dilaksanakan untuk mempamerkan penganalisaan had-laluan dan rekabentuk laluan jalurlebar di dalam air. Kajian had-laluan adalah satu kaedah yang sangat berguna untuk memberikan gambaran kesan laluan ke atas isyarat yang dipancarkan dan juga untuk menilai hasil perambatan tanpa wayar yang strategik. Tujuan kajian ini adalah untuk merekabentuk sistem komunikasi akustik jalurlebar di dalam air, dan melakukan satu kajian komparatif tentang penganalisaan had-laluan komunikasi di dalam air dengan kesan rosotan. Ini dilakukan dengan perisian MATLAB. Kajian ini mendapati bahawa kondisi saluran komunikasi akustik di dalam air pada frekuensi jalurlebar adalah sangat bergantung kepada rosotan di dalam air dan gangguan hingar. SNR juga adalah sangat bergantung kepada frekuensi di dalam jalur frekuensi untuk komukasi akustik di dalam air.

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LIST OF SYMBOLS

AN	-	Ambient Noise Spectrum Level of the environment
D	-	Shipping traffic coefficient
DIr	-	Directivity Index of the receiver
DIt	-	Directivity Index of the transmitter
Eb	-	Energy required per bit of information
F	-	Frequency in kHz
Gr	-	Receiving Antenna Gain
Gt	-	Transmitting Antenna Gain
K_B	-	Boltzmann's constant = $1.38 * 10^{-23}$
LM	-	Link margin
Ln	-	Noise Factor
Ls	-	Free Space Path Loss, spreading and atmospheric attenuation
N0	-	Thermal receiver noise
Pr	-	Received Power, equivalent to SNR (all quantities in dB)
PSL	-	Pressure Spectrum Level of transmitting platform
Pt	-	Transmitted Power
R	-	Data rate
R	-	Range in meters
SNR	-	Signal to Noise Ratio at the receiver

T0	-	Receiver temperature in degrees Kelvin
W	-	Bandwidth
Ws	-	Wind speed m/s
α	-	The attenuation coefficient in dB/km

CHAPTER 1

INTRODUCTION

1.1 Background of the Research

The availability of affordable and sophisticated digital signal processing has enabled modern undersea acoustic communications systems. Advances in this field have opened the door to autonomous sensors and untethered vehicles capable of networked operations in the undersea environment. For radio frequency (RF) communications, link budgeting is commonly used to predict system performance in a representative environment. The link budget estimates the signal level at the receiver for a given transmit power and antenna configuration and accounts for environmental factors such as transmission loss and interference.

This project shows that the link budget can be readily applied to an undersea acoustic communication system using the same principles as the RF link budget. The acoustic link budget combines all terms of the active sonar equation to provide a first order approximation of signal available at the receiver.

Link budget is a method for studying the effect of ambient noise such as wind speed, shipping density and thermal noise on the underwater acoustic signal. It analyses the link margin at the receiver. The link margin is the difference between the required power to noise ratio and the receive power to noise ratio at the receiver.

The link budget for underwater acoustic signal estimates the signal level at the receiver for a given transmit power and antenna configuration and accounts for environmental factors such as transmission loss and interference. Link budget analysis for underwater acoustic channels is considered as one of the means of communication more difficult today. Attenuation coefficient of the underwater acoustic supports deployment to the best acoustic low frequencies and bandwidth available to communicate is very limited. Underwater communications that used wireless acoustic communication have several of applications in underwater war. So, Implementation of security wireless underwater communications is of great important to extend the network war under the water. However, underwater acoustic communication is the effect of ambient noise on the signal so the ambient noise is reduces the signal to noise ratio limited by the result is reduce the link margin. So in this project we will use the link budget analysis for underwater acoustic communication to improve the signal to noise ratio so the result is increase the link margin. The link margin is the difference between the received signal to noise ratio and the required signal to noise ratio.

In the next chapter, we develop a link budget model as a form of the sonar equation. A link budget is a method used for expected the signal to noise ratio (SNR) for given parameters such as transmit power, antenna gain, propagation loss, and interference. This project shows that the link budget can be readily applied to an underwater acoustic communication system using the same principles as the radio frequency (RF) link budget. A theoretical model shows how the link budget changes with varying wind values. The acoustic link budget combines all terms of the active sonar equation to provide a first order approximation of signal available at the receiver (Houdeshell, 2001).

1.2 Problem Statement

The link budget method of acoustic propagation analysis is a simplified technique providing the analyst with a first-order estimate of link performance. There are inherent inaccuracies that must be considered, all of which require incorporation of physics based propagation modeling.

Therefore, the statements of the problems in this research are as follows

1. Low Propagation Speed: Underwater acoustic waves have a propagation speed around 1500m/s .The low propagation speed leads to a large propagation delay.
2. Ambient Noise: The communication link is strongly affected by ambient noise like shipping density, wind speed, thermal noise and animal sounds.
3. Limited Bandwidth: The acoustic frequencies depend on distance since higher frequencies are highly attenuated. Acoustic channels have low bandwidth.

Thus, this study evaluates the link budget necessaries to overcome these problems.

1.3 Objective of the Research

1. To design underwater acoustic communication system operating in frequency band of 9-14 kHz and maximum range is up to 8 Km.
2. To enhance network performance, we design underwater communication system operating in the tow telesonar frequency bands (14-19, 15-20) kHz using M-QAM modulation and compare between Omni-directional transducer and 9dB directional.
3. To study and analyses the effect of wind speed variation on the channel signal to noise ratio (channel SNR) of the system.

1.4 Benefits of Study

Underwater networks that employ wireless acoustic communication have a wide variety of applications in undersea warfare. Therefore, implementing reliable wireless underwater communications is of great importance to the Navy as it extends network centric warfare under the sea. These wireless underwater acoustic applications include networked telemetry between sensors and base stations in littoral waters, submarine communications, control of minefields, and control of Unmanned Underwater Vehicles (UUVs).

REFERENCES

Ali, H. B. (1993). Oceanographic variability in shallow-water acoustics and the dual role of the sea bottom. *Oceanic Engineering, IEEE Journal of*, *18*(1), 31-41.

Burdic, W. S. (1984). *Underwater acoustic system analysis* (Vol. 2). Englewood Cliffs: Prentice-Hall.

Butler, A. L., Butler, J. L., Dalton, W. L. and Rice, J. A. (2000). Multimode directional telesonar transducer. In *Oceans 2000 MTS/IEEE Conference and Exhibition* (Vol. 2, pp. 1289-1292). IEEE.

Dessalermos, S. (2011). Adaptive reception for underwater communications.

Hansen, J. T. (2002). *Link budget analysis for undersea acoustic signaling*. NAVAL POSTGRADUATE SCHOOL MONTEREY CA.

Houdeshell, J. E. (2001). *Bandwidth optimization of underwater acoustic communications systems* (Doctoral dissertation, Monterey, California. Naval Postgraduate School).

Hurt, C. S. (2005). *Effect of wind noise on undersea acoustic network performance and design* (Doctoral dissertation, Monterey California. Naval Postgraduate School).

Kriewaldt, H. A. (2006). *Communications performance of an undersea acoustic wide-area network* (Doctoral dissertation, Monterey California. Naval Postgraduate School).

Lurton, X. (2002). *An introduction to underwater acoustics: principles and applications*. springer.

O'Neal, D. M. (1998). *Comparison of the underwater ambient noise measured in three large exhibits at the Monterey Bay Aquarium and in the inner Monterey Bay*. NAVAL POSTGRADUATE SCHOOL MONTEREY CA DEPT OF PHYSICS.

Pelekanos, G. N. (2003). *Performance of acoustic spread-spectrum signaling in simulated ocean channels* (Doctoral dissertation, Monterey, California. Naval Postgraduate School).

Proakis, J. G. (1995). Digital communications (McGraw-Hill, Inc., 1995).

Rappaport, T. S., Reed, J. H. and Woerner, B. D. (1996). Position location using wireless communications on highways of the future. *Communications Magazine, IEEE*, *34*(10), 33-41.

Sklar, B. (2001). *Digital communications* (Vol. 2). NJ: Prentice Hall.

Sozer, E. M., Stojanovic, M. and Proakis, J. G. (2000). Underwater acoustic networks. *Oceanic Engineering, IEEE Journal of*, *25*(1), 72-83.

Stojanovic, M. (1995, June). Underwater acoustic communications. In*Electro/95 International. Professional Program Proceedings.* (pp. 435-440). IEEE.

Tiwary, K., Sharada, G. and Singh, A. (2011). Underwater navigation using pseudolite. *Defence Science Journal*, *61*(4), 331-336.

Urick, R. J. (1967). *Principles of underwater sound for engineers*. Tata McGraw-Hill Education.

Urick, R. J. (1979). *Sound propagation in the sea*. CATHOLIC UNIV OF AMERICA WASHINGTON DC DEPT OF MECHANICAL ENGINEERING.

Urick, R. J. (1986). *Ambient noise in the sea*. Peninsula Pub.

Waite, A. D. and Waite, A. D. (2002). *Sonar for practising engineers* (Vol. 3). London: Wiley.

Wenz, G. M. (1962). Acoustic ambient noise in the ocean: spectra and sources.*The Journal of the Acoustical Society of America*, *34*(12), 1936-1956.

Wiley, J. (1982). *FUNDAMENTALS OF ACOUSTICS* (Doctoral dissertation, TECHNISCHE HOCHSCHULE DARMSTADT).

Xavier, J. D. M. (2012). Modulation Analysis for an Underwater Communication Channel.

Zyren, J. and Petrick, A. (1998). Tutorial on basic link budget analysis.*Application Note AN9804, Harris Semiconductor*.