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UNDERWATER WIRELESS COMMUNICATION NETWORKS

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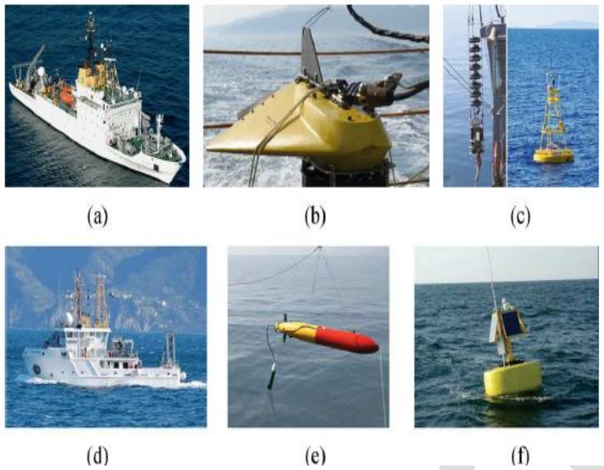
ABSTRACT

In this paper, the MI communication channel has been modeled. Its propagation characteristics have been investigated and compared to the electromagnetic (EM) and acoustic communication systems through theoretical analysis and numerical evaluations. The results prove the feasibility of MI communication in underwater environments. The MI waveguide technique is developed to reduce path loss. The communication range between source and destination is considerably extended to hundreds of meters in fresh water due to its superior bit error rate (BER) performance. To the best of our knowledge this is the first paper that provides an analytical model to characterize the underwater MI communication channel. We propose to reduce costs and energy using relay points (just a simple coil without any energy source or processing device). Those relay coils form a MI waveguide that guides the magneto-inductive waves.

INTRODUCTION

(UWCNs) are constituted by sensors and autonomous underwater vehicles (AUVs) that interact to perform specific applications such as underwater monitoring. Although acoustic waves have been widely accepted by the scientific community as physical transmission medium for UWCNs, they have some important drawbacks: refraction in deep water, temperature gradients and reflections in shallow water (water with depth 100 m). The underwater acoustic signal is degraded due to multipath fading. The large propagation delays, low bandwidth and high bit error rates of the underwater acoustic channel hinder communication as well. These operational limits call for complementary technologies or communication alternatives when the acoustic channel is severely degraded.

Magnetic induction (MI) is a promising physical layer technique for UWCNs that is not affected by multipath propagation and fading. Important applications for shallow water such as diver-to-diver voice and text communications can be developed using this technique. Real-time data transfer between AUVs, or AUVs and underwater sensors are other key applications. Telemetry and remote control from underwater or surface equipment is also possible, since the water to air boundary is crossed by the magnetic component of an electromagnetic signal with relatively low attenuation. Communication between AUVs and docking stations, or control of AUVs from surface vessels and shore is helpful in environmental and military applications such as mine countermeasures during coastal reconnaissance missions. Diver to shore or vessel communication are other interesting applications. In this project, the MI communication channel has been modeled. Its propagation characteristics have been investigated and compared to the electromagnetic (EM) and acoustic communication systems through theoretical analysis and numerical evaluations. The results prove the feasibility of MI communication in underwater environments.


(a) (b) (c)
(d) (e) (f)

The MI waveguide technique is developed to reduce path loss. The communication range between source and destination is considerably extended to hundreds of meters in fresh water due to its superior bit error rate (BER) performance. To the best of our knowledge this is the first project that provides an analytical model to characterize the underwater MI communication channel.

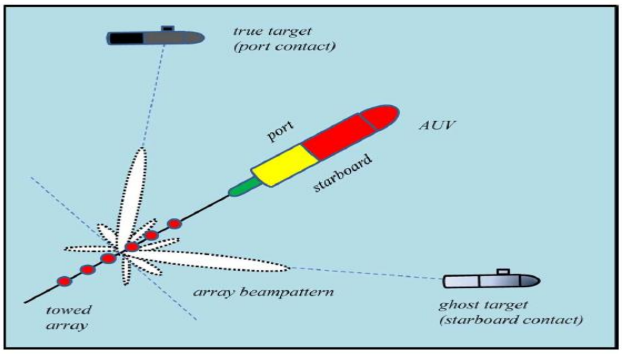
RELATED WORKS

Autonomous systems have a wide range of applications, especially in the underwater domain where it is preferable or mandatory to avoid the human presence. Autonomous underwater vehicles (AUVs) with sensing capabilities then substitute for the human operator, and autonomously work to perform many tasks, including object detection (e.g., underwater mines), interferometry, sea state sensing (e.g., measurement of temperature, conductivity, currents, etc.). But submarine detection and tracking, referred to as anti-submarine warfare (ASW), is one of the most important applications.

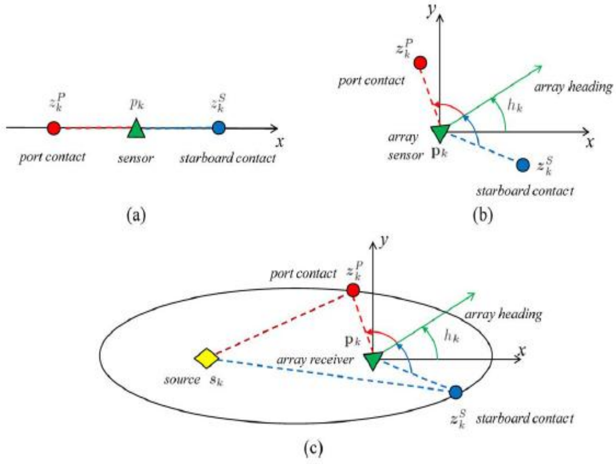
Active ASW systems can be classified as monostatic, when the acoustic source and receiver are co-located, as opposed to multistatic systems in which the sources and the receivers are different entities, space dapart from each other. Many ASW systems are designed according to the multi- static achitecture and the minimum multistatic configuration, consisting of a single source-receiver pair, is referred to as bistatic. Acoustic sources are hull mounted sonars and active sonobuoy sources, while common examples of receivers are towed line arrays. Traditionally these arrays have been towed by submarines or frigates, however this approach is manpower intensive. More recently, alternative approaches have been suggested in which the system is made of distributed mobile and stationary sensors, such as sonobuoys and AUVs.

In contrast with the use of standard assets, these small, low-power, and mobile devices have limited onboard processing and wireless communication capabilities. Due to their low cost and moderate hardware/software complexity, individual sensors can only perform simple local computation and communicate over a short range at low data rates. But when deployed in a large number across a spatial domain and properly interconnected, these primitive sensors can form an intelligent network achieving very high performance with significant features of scalability, robustness, reliability. An overview on underwater wireless sensor networks (WSNs) is provided.

In ASW systems based upon the WSN paradigm and employing AUVs ,receiving sensors have limited on board computational capabilities and therefore linear arrays with a conventional (rather than adaptive) beamformer are employed. In this regard, one key fact is that single line array receivers are cylindrically symmetric: They cannot discriminate if a detected echo comes from the port or from the starboard ,i.e., they suffer from port-starboard ambiguity. Such an ambiguity complicates the detection and tracking algorithms and may cause severe performance degradation. Indeed, ambiguities area challenging issue in many WSN applications involving sensors with very limited capabilities, see e.g., Several approaches have been proposed to overcome these difficulties, including multiline arrays ,e.g., twin arrays and triplet arrays. However the use of multiline arrays requires the use of a higher number of hydrophones to achieve the resolution of a single line array. Given that in ASW applications the sonar system works at low and mid frequency, in order to achieve the desired directivity the minimum number of elements is often prohibitively large and the choice of a single linear towed array could be mandatory when AUVs are in use. As a consequence, with this system solution, we are faced with the port-starboard(PS) ambiguity problem, which plays as an additionals ource of uncertainty enriching the classical measurement-origin uncertainty (MOU) setup that is the standard reference for dealing with missed detections and false alarms in multisensor/multitarget systems. The observation model resulting by including the PS ambiguity into the MOU model will be referred to as MOU-PS. The PS ambiguous contacts (also called ghosts), as opposed to false alarms, are coherent in the sense that a tracker would always generate two tracks the true one and the ghost that are symmetric with respect to the array heading



Several approaches have been proposed to overcome these difficulties, includeing multiline arrays,e.g., twin arrays and triplet arrays. However the use of multiline arrays requires the use of a higher number of hydrophones to achieve the resolution of a single line array. Given that in ASW applications the sonar system works at low and mid frequency, in order to achieve the desired directivity the minimum number of elements is often prohibitively large and the choice of a single linear towed array could be mandatory when AUVs are in use. As a consequence, with this system solution, we are faced with the port-starboard(PS) ambiguity problem, which plays as an additional source of uncertainty enriching the classical measurement-origin uncertainty (MOU) set up that is the standard reference for dealing with missed detections and false alarms in multisensor/multitarget systems. The observation model resulting by including the PS ambiguity into the MOU model will be referred to as MOU-PS. The PS ambiguous contacts (also called ghosts), as opposed to false alarms, are coherent in the sense that a tracker would always generate two tracks–the true one and the ghost–that are symmetric with respect to the array heading.



Thus, in order to resolve the PS ambiguity, some degree of diversity within the collected data is needed. Since the true contacts are alllocated around the target, while the ghost echoes are located at the specular position with respect to the array heading, as patial diversity can be obtained by using different sensor antennas, each with its own location / orientation with respect to the target. Indeed, if antennas' headings are not aligned, then the ghost reports at different sensors are located at different areas of the surveillance region, and therefore they can be more easily classified as ghosts. Inaddition, time diversity can be exploited even with a single antenna array, provided that It is able to perform multiple scans with time-varying locations/orientations. Clearly,this latter approach is fruitful when the target dynamics are sufficiently slow as compared to these multiple scans. Any sensible observation models for ASW is inherently nonlinear, and consequently the posterior distribution is not Gaussian. One either tries to linearize the problem (leading to Extended/Unscented Kalman Filter, range-bearing converted measurements, etc.) or one admits the complexity and appeals to a fully Bayesian method: a particle filter. And if one does so, one might as well include the PS ambiguity to the observation model and solve it optimally.

A very useful technique for ASW is the Target Motion Analysis (TMA), typically used for passive arrays (only bearing information), where there is no target observability, e.g., In order to "solve" the target non-observability the platform has to maneuver, using some information about the target trajectory, collecting data which allow a meaningful estimation of the target state.An analogous concept is present also in the PS ambiguity, i.e., TMA could suggest an *optimal* AUV maneuver plan. Clearly this is complementary to the proposed procedure: We derive the optimal Bayesian filtering to track the target state (position and velocity) under the MOU-PS model. To the best of our knowledge, this is the first attempt to derive the optimal fusion rule for multisensor tracking in the presence of measurements of uncertain origin *and* port-starboard ambiguity.

We first attack the problem from an analytical point of view by deriving the exact likelihood of the data under the MOU-PS model, and then analyze the performance of the tracking system via computer experiments. The final validation of the proposed approach, however, is provided by an extensive experimental campaign using real-world data collected during sea trial experiments, conducted by the NATO Science and Technology – Centre for Maritime Research and Experimentation (CMRE, formerly known as SACLANTCEN and NURC) in 2011 and 2012. The NATO research vessel (NRV) *Alliance*, the coastal research vessel (CRV) *Leonardo*, and CMRE's underwater network with multistatic sonar system have been used during the experimentations. Some results of these underwater experimental campaigns are here reported.

EM communication is only recommended for very short range applications due to the propagation properties of EM waves. In, Cheet al.advocate using EM signaling, coupled with digital technology and signal compression techniques in reliable, connector less, and short range data link applications demanded by the oil industry, military, and environ-mental operations.

MI is a promising physical layer technique for underwater wireless communication that propagates underwater, since the attenuation rate of magnetic fields does not vary from that of

air due to the similar magnetic permeabilities of both media. In addition, since the magnetic field is generated in the near-field, it is non-propagating. The MI field does not have multipath modes. As a result, multipath fading is not an issue.

In addition, as opposed to acoustic communication, it does not suffer large propagation delays. Therefore, MI is strongly recommended over short ranges where acoustic noise levels are very high or multipath interference is severe. Furthermore, it is not so liable to shadowing

How-ever, it is restricted in the distance it can offer effective data rates and its operation is limited in noisy environments. EM and MI systems have a limited range of operation but they are immune to acoustic noise and provide the required signal bandwidth depending on the applications requirements.

OUR CONTRIBUTION

In the ASW scenario considered here there is only one target of interest. However it is possible to have several target-like objects (e.g., large gross tonnage vessel, rocks, etc.) moving in the surveillance region. For trim notation we in this work assume only a single target, but the extension to the multi-target case is straightforward. Let us consider a WSN made of sensors (AUVs towing acoustic array antennas) monitoring a certain surveillance region inside which a single target is sailing.

The WSN is tasked to estimate the target kinematic state at each time scan. Assuming that the target and the vehicles sail in shallow water ( ) and the sonar system works at mid-frequency( ) and long-range ( ), the geometry can be considered approximately planar for the sound propagation and the water depth can be neglected. In fact the range distance between the target and the receivers (or source-target-receiver in the bistatic setup) are typically in the order of kilometers while in many scenarios the water depth does not exceed a few hundreds of meters, thus making the sound propagation similar to that inside a planar waveguide.

Actually, the specific depths of the target, receivers and sources may become important in terms of signal-to-noise ratio (SNR) due to the constructive/destructive interference in a multipath environment, and part of the current research focus on strategies that can be adopted in order to maximize (or minimize from the point of view of the target) the SNR and consequently the target detection probability. However, in this work we neglect these effects and assume for simplicity that the problem is two dimensional, and that the SNR is uniform and constant in, leading to false alarms uniformly distributed inside the surveyed area and to a constant detection probability. These assumptions are commonly adopted in the topical literature, see e.g., But of course these assumptions are “relaxed” by Nature herself when we test our approaches on the data set ExPOMA12, which includes quite a few additional unmodeled acoustic effects resulting from bistatic geometry, reverberation, bathymetry, etc.

OPTIMAL BAYESIAN INFERENCE WITH PS AMBIGUITY

In the Bayesian approach to dynamic state estimation, the goal is to construct the posterior probability density (pdf) of the state based on all available information, including the set of received measurements. Since this pdf embodies all available statistical information, it contains the complete solution to the estimation problem, and the optimal (with respect to any criterion)

Estimate of the state may be obtained from the posterior. The posterior of the target’s state (1), indicated by $\mathcal{P}(\boldsymbol{x}_k | Z_{1:k})$ is given by the Bayes’ rule

$$\mathcal{P}(\boldsymbol{x}_k | Z_{1:k}) = \frac{\mathcal{L}_k(Z_k | \boldsymbol{x}_k)\,\mathcal{P}(\boldsymbol{x}_k | Z_{1:k-1})}{\mathcal{P}(Z_k | Z_{1:k-1})}$$

Where the prior at time is given by

$$\mathcal{P}(\boldsymbol{x}_k | Z_{1:k-1}) = \int \mathcal{P}(\boldsymbol{x}_k | \boldsymbol{x})\,\mathcal{P}(\boldsymbol{x} | Z_{1:k-1})\, d$$

And $P(x_{k/}x)$ is ruled by the dynamic model (1). The scaling factor can be computed by

$$\mathcal{P}(Z_k | Z_{1:k-1}) = \int \mathcal{L}_k(Z_k | \boldsymbol{x})\,\mathcal{P}(\boldsymbol{x} | Z_{1:k-1})\, d\boldsymbol{x}.$$

Given that the sensors are conditionally independent, the likelihood $L_k(Z_k|x_k)$ can be factorized

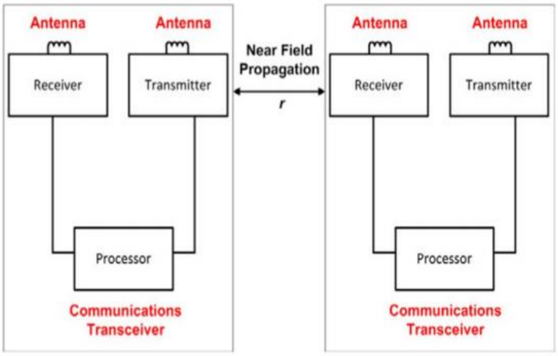
$$\mathcal{L}_k(Z_k | \boldsymbol{x}_k) = \prod_{s=1}^{N_s} \mathcal{L}_{s,k}(Z_{s,k} | \boldsymbol{x}_k),$$

Where $L_{s,k}(Z_{s,k} | x_k)$ is the likelihood of the measurements observed by the S th sensor at time , and is derived in the following subsection, based on the MOU-PS model The assumption of conditional independence is quite intuitive, especially if the sensors are not co-located; and it is commonly accepted in the tracking literature. Basically we have that neither are the false alarms of a sensor statistically correlated to those of the others, nor are measurement noises dependent, and that the target detection events are independent Bernoulli random variables with parameter P_D Regarding the classic “track-to-track fusion” formulation, note that even if the sensors are conditionally independent after the filtering stage the state estimates are in general *dependent* due to the common process noise. In our approach we fuse and filter at the same time; the issue is obviated.

Note that the data from the sensors are *not* identically distributed as each sensor has its own location/orientation with respect to the target, which can be time varying. This characteristic is a key feature to solve the PS ambiguity because the *true* contacts are all located around the target, instead the *ghost* contacts are located at the specular position with respect to the heading of the sensor. If sensors’ headings are not aligned then the ghost reports are located in different areas of the surveillance region and then aremore likely to be false. When only a single sensor is present, the dynamic of the ghost contacts can be quite different from that of the real ones because of they would be influenced by the dynamic itself of the sensor. Then multiple dynamic sensors can be considered as the most suitable setup to solve the PS ambiguity.

USING MAGNETIC INDUCTION:

An underwater communication system that uses magnetic induction transmission. We propose to reduce costs and energy using relay points (just a simple coil without any energy source or processing device). Those relay coils form a MI waveguide that guides the magneto-inductive waves. A similar approach has been proposed. However, the authors focus on underground communications. This analysis cannot be applied to underwater communications because the propagation medium is different. The communication medium is no longer mostly soil and rock but fresh water or sea water. Consequently, the medium properties as well as operating frequencies for near-field communication are different. Those differences affect the path loss for the MI and the MI waveguide communication systems.

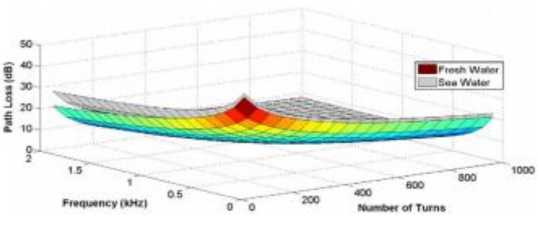


In addition, in sea water the path loss is severely affected by the induced eddy currents because of the conductive nature of sea water. Furthermore, in this paper the performances of the MI and MI waveguide sys-tems have been compared in underwater environments not only to the EM system but also to the acoustic system. The major characteristics of acoustic, EM and MI waves in underwater environments have been summarized. There is a tradeoff between quality of service (QoS)-distance-type of system. Acoustic transmission outperforms EM and MI communications for long-distance applications. How-ever, it is restricted in the distance it can offer effective data rates and its operation is limited in noisy environments. EM and MI systems have a limited range of operation but they are immune to acoustic noise and provide the required signal bandwidth depending on the applications requirements. Magneto-inductive signals in the extremely low frequency (ELF)to very low frequency(VLF)range(usually in the range of 500 to 3000 Hz) are used for underwater communication. Already licensed aeronautical and marine communication systems use the following frequencies. Airband refers to the group of frequencies in the very high frequency (VHF) radio spectrum used for radio communication in civil aviation. Trans-oceanic aircraft also carry high frequency (HF) radio and satellite transceivers. Marine VHF radio is used in coastal waters and relatively short-range communication between vessels and to shore stations. 2182 kHz is a medium-wave frequency used for marine emergency communication. There-fore, we conclude there is no electromagnetic interference to already licensed aeronautical and marine communication systems from MI communications.

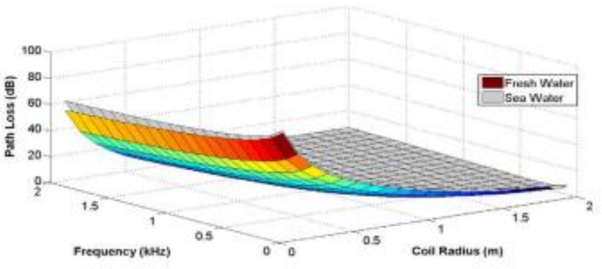
In this paper, the path loss of the MI system has been derived assuming that the load impedance is equal to the complex con-jugate of the input impedance at port 2. Therefore, there are no reflected waves and the maximum power is transmitted to the load. Perfect matching is provided at only one frequency. Any deviation from the central frequency causes power reflections and increases the path loss. The condition that the coils are resonant in the MI waveguide is applied only at a single frequency as well. Therefore, the bandwidth of the MI and MI waveguide systems should be analyzed.

Short transmission ranges (up to 9 m) the path loss and BER are lower with the MI system for fresh water compared to the electromagnetic and acoustic communication systems. The performance of the MI system in sea water is also good, although the path loss values are higher than in fresh water due to the electrical conductivity of sea water. The path loss with MI communication is diminished with the coil radius and the number of turns.

MI systems operate typically over very short range (a few meters). A near-field magnetic induction communication system is a short range wireless physical layer that communicates by coupling a tight, low-power, non-propagating magnetic field between devices. A transmitter coil in one device modulates a magnetic field which is measured by means of a receiver coil in another device.



Path loss for MI comm. as a function of frequency and number of turns



Path loss for MI comm. as a function of frequency and coil radius

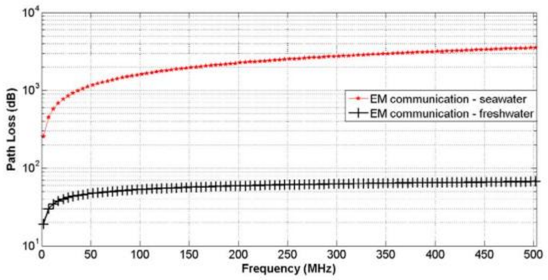
The sonar parameter transmission loss (TL) or path loss is defined as the accumulated decrease in acoustic intensity when an acoustic pressure wave propagates outwards from a source. This magnitude can be estimated by adding the effects of geo-metrical spreading, absorption and scattering. In very deep water, the sound rays emitted by a source are bent downward due to decreasing temperature until the increase in pressure bends the sound rays upward in the deep isothermal layer. When the refracted sound rays approach the surface, they intersect in areas of high intensity named convergence zones.

The magnetic antennas should preferably work at low frequencies in sea water due to the attenuation because of the induced eddy currents in a conductive medium. Eddy currents generated by the AC magnetic field flow in salt water and waste energy, since they produce a negative moment that bucks the transmitted moment and modifies the field distribution.

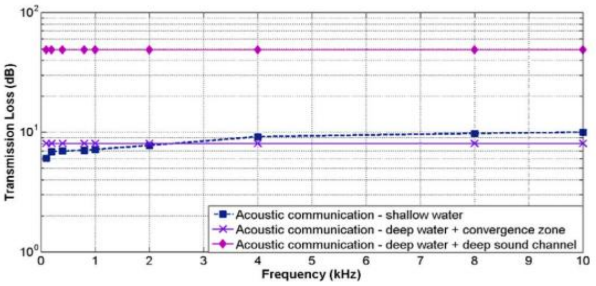
The reason is that the attenuation constant in sea water increases with frequency but in fresh water does not depend on this parameter and the value is very small (0.2093 Np/m). The phase constant is also higher in sea water for frequencies lower than 444 MHz.

RESULTS & DISCUSSION

The path loss as a function of the radius (of the transmitter and receiver coils) and frequency is shown for fresh water and sea water.



Where alpha is given in meters, is given is Np/m and is given in radian/m. The propagation of EM waves in sea waterand infresh water is analyzed for each case and different values for and are obtained according to . Sea water is a high lossy medium where the electrical conductivity is about two orders higher than that of fresh water mainly due to its great salinity. It is convenient to consider the solutions for the conduction band and the dielectric band ,where is the permittivity (F/m, is the relative permittivity of water) and is the electrical conduc tivity. In sea water S/m and the transition frequency 888 MHz. Since in sea water for most frequencies, the expressions of and for good conductors can be applied. In fresh water 0.01 S/m and the transition frequency 2 MHz. Since in fresh water for most frequencies, the expressions of and for good dielectric can be applied.



The differences between the channel models are highlighted as follows. In shallow water, sound is propagated to a distance by repeated reflections from the surface and bottom . In deep water, the basic propagation paths “convergence zone” and “deep sound channel” are introduced. In very deep water, the sound rays emitted by a source are bent downward due to decreasing temperature until the increase in pressure bends the sound rays upward in the deep isothermal layer. When the refracted sound rays approach the surface, they intersect in areas of high intensity named convergence zones. The deep sound channel is a horizontal layer of water in the ocean at which depth the sound velocity profile has a minimum.

CONCLUSION

While the state-of-the-art in the context of AUV network is a heuristic approach to disambiguation, our experiments show that the port-starboard ambiguity can be indeed resolved in an optimal way, i.e., by including the ambiguity in the analytical model of the observations and deriving the full Bayesian posterior distribution of the target state. In addition, the proposed disambiguation comes at no additional cost in terms of computational complexity, given a particle filtering implementation of the Bayesian filtering iterations. Possible directions for future studies include the adaptive optimization of the sensors' deployment and dynamics, using techniques like dynamic programming and stochastic control. Considering the shallow water environment the tracker can be also enhanced using optimization strategies to maximize the SNR and consequently the target detection probability. Another future work is the extension of the proposed procedure to a scenario with multiple targets.

The MI waveguide technique reduces path loss and extends communication ranges. For fresh water it achieves better results than the ordinary MI and the EM wave systems, and outper-forms the acoustic system under all propagation phenomena. Because of its superior BER performance, the transmission ranges have been improved moderately in sea water and have been extended considerably to hundreds of meters in fresh water. This opens the potential for a number of applications to emerge. Therefore, we recommend MI (especially MI waveguide) as a complementary technology when the acoustic channel is severely degraded. MI communication is a very promising technique to re-establish communication after the acoustic channel is deteriorated due to the presence of shadow zones. The system interoperability of MI with other existing technologies and its superior BER performance are essential properties in favor of the spread of this technology.

REFERENCE

[1] I. F. Akyildiz, D. Pompili, and T. Melodia, "Underwater acoustic sensor networks: Research challenges,"Ad Hoc Netw., vol. 3, no. 3, pp. 257–279, Mar. 2005.

[2] J.-H. Cui, J. Kong, M. Gerla, and S. Zhou, "The challenges of building mobile underwater wireless networks for aquatic applications,"IEEE Netw., vol. 20, no. 3, pp. 12–18, May–Jun. 2006.

[3] M. Rhodes, D. Wolfe, and B. Hyland, "Underwater remote sensing," U.S. Patent 2010/0159827, June 24, 2010.

[4] M. Rhodes, B. P. Hyland, and A. Jaffrey, "Subsea transfer system pro-viding wireless data transfer, electrical power transfer and navigation," U.S. Patent 2011/0177779, Jul. 21, 2011.

[5] X.Che, I.Wells,G.Dickers,P. Kear,and X.Gong, "Re-evaluation of RF electromagnetic communication in underwater sensor networks," IEEE Commun. Mag., vol. 48, no. 12, pp. 143–151, Dec. 2010.

[6] L.Liu,S.Zhou,andJ.-H.Cui,"Prospects and problems of wireless communications for underwater sensor networks,"Wiley Wireless Commun. Mobile Comput., vol. 8, pp. 977–994, 2008.

[7] J. J. Sojdehei, P. N. Wrathall, and D. F. Dinn, "Magneto-inductive (MI) communications," inProc. MTS/IEEE Conf. Exhib. OCEANS, 2001, vol. 1, pp. 513–519.

[8] I. S. Bogie, "Conduction and magnetic signalling in the sea. A background review,"Radio Electron. Engineer, vol. 42, no. 10, pp. 447–452, Oct. 1972.

[9] Z. Sun and I. F. Akyildiz, "Magnetic induction communications for wireless underground sensor networks,"IEEE Trans. Ant. Propag., vol. 58, no. 7, pp. 2426–2435, Jul. 2010.

[10] K. Finkenzeller, RFID Handbook. Chichester, U.K.: Wiley, 2001.

[11] C. A. Balanis, Antenna Theory: Analysis and Design. Hoboken, NJ: Wiley-Interscience, 2005.

[12] C. A. Balanis, Advanced Engineering Electromagnetics.NewYork: Wiley, 1989.

[13] M. C. Domingo, “Overview of channel models for underwater wireless communication networks,”Elsevier J. Phys. Commun., vol. 1, no. 3, pp. 163–182, 2008.

[14] R. E. Francois and G. R. Garrison, “Sound absorption based on ocean measurements: Part I: Pure waterand magnesium sulfate contribu-tions,”J. Acoust. Soc. Amer., vol. 72, no. 3, pp. 896–907, 1982.

[15] R. E. Francois and G. R. Garrison, “Sound absorption based on ocean measurements: Part II: Boric acid contribution and equation for total absorption,”J. Acoust. Soc. Amer., vol. 72, no. 6, pp. 1879–1890, 1982.