Renewable Sources – A Genetic Perspective and Application Architecture for Improved Underwater Astronomy Observations

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Abstract— **The conduct of underwater astronomy is an important scientific investigation and procedure. Underwater astronomy observations require the provisioning of power to operate underwater telescopes. The observation should be done while enhancing the angular resolution and not constituting an extra load on the grid. Underwater astronomy uses underwater telescopes that are needed to ubiquitously detect neutrinos. The research proposes a novel light interception approach for the generation of electricity in the deep underwater environment. The proposed energy utilizes bio-engineered bioluminescence to realize electrical energy for underwater telescope operation. The use of the proposed energy source enables underwater telescopes to be located at different underwater locations with significant capacity to enhance the baseline. The use of the proposed approach for powering underwater telescopes enhances the observation i.e., angular resolution by an average of (34.8 – 47.8)%.**

Keywords – Underwater Astronomy ; Applied Genetics ; Underwater Science ; Angular Resolution ; Communication Models

I. INTRODUCTION

Underwater astronomy is an important scientific investigation. It involves the use of underwater telescopes that are deployed in the underwater environment [1–2]. The underwater telescopes require access to electricity, and it is infeasible for underwater telescopes at significant ocean depths to rely on the terrestrial grid. In addition, it is important for underwater telescopes to be capable of detecting neutrinos at improved angular resolution.

Therefore, underwater energy sources are required for underwater telescopes. Therefore, it is important to design underwater energy sources for underwater telescopes. The use of renewable energy sources is expected to increase due to their environmental benefits [3–4]. Solar energy is a recognized source of renewable energy that uses solar panels which intercepts the incident solar radiation. Solar energy farms are widely used in terrestrial environments [5]. Solar panels can also be located in aerial [6] and space [7] environments. The use of the terrestrial environment for hosting solar panels has a low exposure. The reduced exposure is inferred because the earth is 70% water [8–9].

However, it is challenging to host solar panels in the underwater environment due to poor solar radiation penetration [10–11]. Therefore, an alternative light source capable of providing the input to solar panels is required. A feasible light source is bioluminescence. Bioluminescent marine organisms radiate low intensity light. They are present at different depths in underwater environments [12–13]. Bioluminescent marine organisms can be harnessed as a potential source of renewable energy. However, this requires further consideration. The use of this energy source utilizes the ocean's large surface area as a platform for light interception.

An increase in the light intensity is desired and requires an adaptation of the light intensity of bioluminescent organisms. The adaptation requires a genetic modification of bioluminescent organisms to increase their light intensity. An increased light intensity yields electric energy output when intercepted by a solar panel in the underwater environment.

The contribution of the research is the design of a power source that support the ubiquitous deployment of underwater telescopes. The ubiquitous deployment requires the availability of power sources at all underwater locations. It also increases exploration potential. The design of a biological based light source is presented. The biological based light source enables the derivation of electrical output from light interception entities i.e., solar panels in the underwater environment. The research contributions are:

1) The research proposes underwater solar systems. In the proposed approach of underwater solar systems, genetically modified marine bioluminescent organisms are used. The modification aims to increase the parameters associated with the bioluminescence. The parameters being increased are the light intensity, and the duration.
2) Second, the research presents different application perspectives with focus on use approaches and system design. The design enables the harnessing of the derived electrical energy in underwater technologies.
3) Third, the research presents the integration of the proposed source with deployed underwater telescopes. In addition, the research formulates the underwater angular resolution for the existing, and proposed approach. The existing approach is one where the proposed power source is not used. In this case, the underwater telescopes are powered via onboard batteries [18]. The proposed approach decouples underwater telescope deployment from power provisioning. The decoupling of power provisioning and underwater telescopes enables the realization of ubiquitous underwater astronomy. In ubiquitous underwater astronomy, an improved and a dynamic angular resolution can be realized.

The rest of the presented research is organized as follows. Section II describes the problem. Section III presents the design perspective for realizing useful bioluminescence in marine organisms. Section IV presents the integration of the proposed power source into underwater telescopes. Section V formulates the angular resolution. Section VI is the performance evaluation. Section VII is the conclusion.

II. PROBLEM DESCRIPTION

The considered scenario comprises multiple underwater telescopes being used in underwater astronomy. The underwater telescopes are being deployed and used by a capital constrained organization seeking to improve the angular resolution. In addition, the underwater telescopes transmit data to the terrestrial environment via deployed autonomous underwater vehicles. Autonomous underwater vehicles have own power sources. They do not share power sources with the underwater telescopes. Autonomous underwater vehicles also relay observational data from the underwater telescopes to the external networks for access by scientists.

Let the set of underwater telescopes be denoted as ϕ such that:

$$\phi = \{\phi_1, \phi_2, \dots, \phi_A\} \quad (1)$$

In addition, let the underwater location indicator of the telescope $\phi_a, \phi_a \in \phi$ in the location $l_x, l_x \in l, l = \{l_1, \dots, l_X\}$ at the epoch $t_y, t_y \in t, t = \{t_1, \dots, t_y\}$ be given as $I_1(\phi_a, l_x, t_y) \in \{0,1\}$. The underwater telescope ϕ_a is at the location l_x at the epoch t_y when $I_1(\phi_a, l_x, t_y) = 1$. In addition, the underwater telescope ϕ_a is not at the location l_x at the epoch t_y when $I_1(\phi_a, l_x, t_y) = 0$. Furthermore, the angular resolution for telescopes at the locations l_x and $l_{x+1}, l_{x+1} \in l$ at the epoch t_y is denoted as $\gamma_1(l_x, l_{x+1}, t_y)$. The realization of the angular resolution $\gamma_1(l_x, l_{x+1}, t_y)$ requires that $I_1(\phi_a, l_x, t_y) = 1$ and $I_1(\phi_a, l_{x+1}, t_y) = 1$ holds true. Furthermore, let the availability of a power source at the location l_x at the epoch t_y be denoted as $I_1(l_x, t_y) \in \{1,0\}$. The power source is available and not available at the location l_x at the epoch t_y when $I_1(l_x, t_y) = 1$, and $I_1(l_x, t_y) = 0$, respectively. The existing power source supports the realization of the target angular resolution $\gamma_1(l_x, l_{x+1}, t_y)$ when $I_1(l_x, t_y) = 1$, and $I_1(l_{x+1}, t_y) = 1$. The realization of the target angular resolution $\gamma_1(l_x, l_{x+1}, t_y)$ is challenging when : (1) $I_1(l_x, t_y) = 1, I_1(l_{x+1}, t_y) = 0$, (2) $I_1(l_x, t_y) = 0, I_1(l_{x+1}, t_y) = 1$, or (3) $I_1(l_x, t_y) = 0, I_1(l_{x+1}, t_y) = 0$. In this case, the design, and deployment, of another power source that supports underwater telescope ubiquity is required.

I. GENETIC RELATED PARAMETERS

Bioluminescence is a biological effect that converts chemical energy to light energy. It benefits from enzymatic driven reaction [14–15]. The concerned enzyme is the luciferase enzyme [16–17]. The occurrence of bioluminescence is the output of a process of the enzymatic oxidation of a lucifern substrate by luciferase enzyme. Different luciferase enzymes have varying substrates (according to species), protein size, and substrate. A variation of the luciferase enzymes and reaction conditions leads to a case where the emitted light has varying wavelengths [18].

Therefore, the genetic i.e., chemical parameters that influence bioluminescence are enzyme and reaction related. The enzyme and reaction related parameters are inferred to be: (1) Enzyme volume, (2) Enzyme concentration, (3) Protein Size, (4) Protein clusters in concerned organism, (5) Number of substrates, and (6) Substrate volume.

An adaptation of the genetic parameters and variables enables the variation of the duration of bioluminescence. Besides, the duration and the intensity of the emitted light can also be varied via the adaptation of these genetic parameters.

In harnessing bioluminescence in renewable energy applications, it is important to obtain a high light intensity and long duration. The genetic modification of bioluminescent marine animals is considered as a solution path.

II. DESIGN PERSPECTIVES

The aim of harnessing bioluminescence in the presented research is generating light energy of sufficient intensity that will yield electricity when incident on the underwater solar panel. In realizing incident light of sufficiently high intensity, the use of an array of incident light sources becomes beneficial. Given that a bioluminescent organism can provide light intensity enabling the derivation of 10mW i.e., $1x10^{-2}$ W from the underwater solar panel (after genetic editing). Given that the enclosure hosts $1x10^{6}$ organisms in an enclosure. In the case where the diameter of each organism is $1x10^{-4}$ m. The hosting of this significant number is feasible due to the small dimensions of bioluminescent organisms. In this case, the enclosure dimension is 100m. Therefore, associated total power output from the light interception entity is 10 kW. Therefore, the use of ten enclosures hosting bioluminescent organs providing up to 100 kW is beneficial. In the application approach being presented with focus on underwater astronomy, the enclosures are not linked to form a connected grid. Instead, they are deployed to different underwater locations. In these locations, the deployed enclosures host different arrays of underwater telescopes. The KM3NeT report recognizes that the power requirement for underwater telescopes is 50kW [19].

An additional requirement is that a sufficiently long duration of high intensity should be achieved. An array of incident light sources can be realized by grouping a significant number of bioluminescent organisms. The concerned organisms are in different regions within the underwater environment. In each region, the group(s) of bioluminescent organisms are hosted in an enclosure. The enclosure is hosted in a manner such that its light output is incident on the underwater light interception entity. Each light interception entity i.e., solar panel receives incident light from multiple enclosures. The use of multiple enclosures i.e., enclosure array has been motivated by benefits of using arrays in wireless networks. In wireless networks, antenna arrays are typically used to detect radio signals propagating in different directions. Antenna arrays comprising single closely spaced antenna elements also radiate a stronger signal. The radiation of a stronger signal in antenna arrays implies increase in coverage range.

The effect of light diffusion and opacity reduce the incident light magnitude. The degrading role of light diffusion and opacity are reduced by limiting the distance between the enclosure and the light interception entity. An important parameter to be considered in this regard is the absorption effect of water alongside the degrading role of light diffusion, and associated opacity. Hence, the enclosure–light interception entity distance is an important parameter. In the proposed solution, the enclosure–light interception entity (solar panel) distance is small and is in the order of tenths of a millimeter. This small distance has been chosen because of the need to reduce the amount of light that is absorbed before being incident on the light interception entity i.e., the solar panel in the underwater environment.

A light interception entity i.e., solar panel receiving light from an array of enclosures is presented in Figure 1. Figure 1 shows the case of a light interception entity i.e., solar panel in an underwater environment. It is in a region where no component of penetrating sunlight is detectable, and capable of serving as the incident light source for triggering electricity output. In Figure 1, each enclosure hosts a significant number of genetically modified bioluminescent organisms. Each enclosure is provided with food sources. The provisioning of food source enables the production of light by bioluminescent organisms in each enclosure. The amount of food provided in each enclosure is intended to last the intended use duration. In Figure 1, the output of the light interception entity is the generated electricity which is stored aboard a battery. The stored electricity is used in providing power for different underwater applications.

The output of the system whose model is presented in Figure 1 is in the order of tens of 10kW. The realization of a higher power output can be realized by increasing the concentration of bioluminescent organisms in the enclosure. An increase in the concentration of the bioluminescent organisms leads to an increase in the light intensity. The increasing light intensity leads to an increase in the associated total power. Therefore, the output of the system whose model is presented in Figure 1 can be significantly increased.

Furthermore, the enclosure in Figure 1 can be used in a manner with localization to an application. In this case, multiple enclosures are conformal to the surface of an underwater technology and application. The light interception entities are also present in this integration.

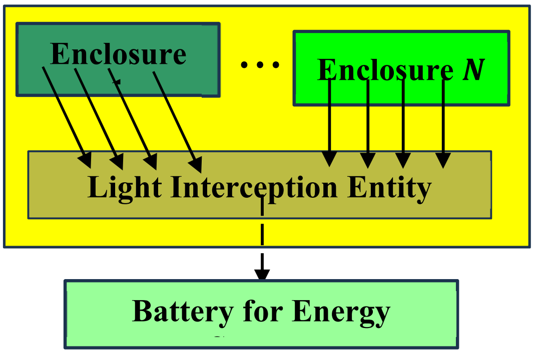

Figure 1: Proposed approach showing how the light interception entity receives light from an enclosure array.

In the design, the electricity output from the light interception entities is used to power the hosting technology. The integrated perspective is suitable for mobile and non-mobile underwater technologies. Examples of suitable applications in this regard are the subsystems of: (1) Autonomous underwater vehicles (AUVs), and (2) Underwater data centers (UDCs). AUVs and UDCs are recognized to play an important role in applications such as communication networks [20–21]. Therefore, the use of the proposed renewable energy system is beneficial to power sub-components of communication system entities.

I. PROPOSED SYSTEM INTEGRATION

The existing conduct of underwater astronomy requires that underwater telescopes host their own power source. Alternatively, underwater telescopes can use energy from the conventional grid via an onshore power station [19]. The reliance on the grid increases the load and should be avoided. This is because of the need to increase power security and availability.

The provision of the proposed power source enables the deployment of underwater telescopes in a transparent manner. This is because underwater telescopes do not have to address the overhead arising from the necessity of providing electrical power. Underwater telescope entity providers (UTEPs) rely on power from the proposed bioluminescent power source. The underwater telescope entities (UTEs) are connected to interfaces on the proposed bioluminescent power module entity (BPME). The relations between the UTEs, UTEPs, and the BPME is presented in Figure 2. The scenario in Figure 2 shows the case of three UTEs i.e., UTE 1 , UTE 2, and UTE 3 are connected to the BPME via interfaces. The interface between the UTEs and the BPME enables the derivation of power from the BPME. The derivation of power in this manner enables the functioning of UTE. Data acquired by the UTE is transmitted to scientists via a network for processing and analysis. In Figure 2, the BPME has a power capacity in the tens of kW. The UTEs, UTE 1, UTE 2, and UTE 3 derive their operational power from the BPME. Each of the UTEs are connected to the BPME via their own interface. Furthermore, each UTE is connected to AUVs for transferring and providing access to observational data.

In Figure 2, the UTEP can deploy multiple telescopes i.e., UTE 1, UTE 2, and UTE 3. The deployment of multiple telescopes can be done in a manner with limited overhead. The UTEP does not need to be significantly considered about providing power. Instead, the UTEP deploy UTEs that utilize power from the BPME hosting the proposed power source. Being able to deploy the UTEs and BPME in this manner is beneficial.

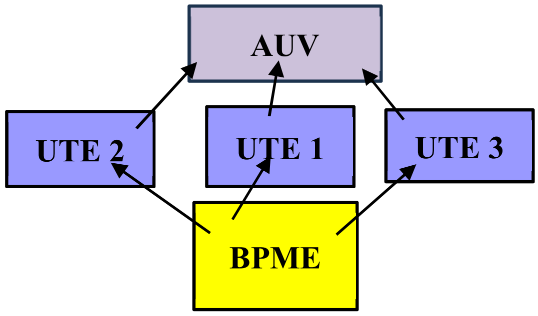

Figure 2: Relations between the BPME and the UTEs i.e., UTE 1, UTE 2, and UTE 3.

The benefit arises because a high underwater angular resolution is achievable as more UTEs can be deployed over a longer baseline and wider area. A high underwater angular resolution arises because of the ability to achieve high UTE separating distance. The realization of high distance arises because of the decoupling between UTEP, UTE and the BPME.

An improved angular resolution is beneficial. This is because it increases the area of the underwater environment where neutrinos can be observed. The significant increase in the area arises because BPMEs can be deployed into any underwater location and provide support to underwater telescopes.

In addition, the research considers how the use of the energy stored in the BPME influences the neutrino detection by UTEs. It is important that energy depletion aboard the BPME does not affect the transfer of data by the observing UTE. A consideration of this challenge is deemed necessary because UTEs execute the task of neutrino detection and also transmit observation related data. Energy depletion in this case occurs due to the occurrence of low light intensity in the genetically modified bioluminescent algorithms yield a sub–optimal output. The consideration of such a scenario is deemed necessary to consider the sub–optimal performance of the genetic modification process.

The UTE functions in two modes i.e., observation and data transmission mode as seen in Figure 3. In Figure 3, the operation of both modes derives their operational power from the BPME. In observation mode, the UTE executes the task of neutrino detection. The data arisen from the observation are transmitted by the UTE in data transmission mode. The UTE transitions between the observation and data transmission modes.

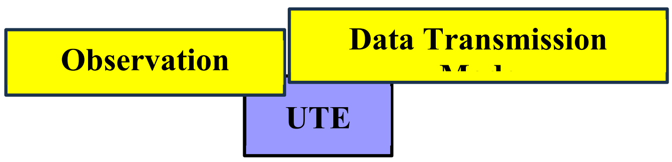

Figure 3: Operational modes of the UTE.

Two types of transitions are feasible in this case. These are the (1) Observation to Data transmission mode, and (2) Data Transmission to Observation mode. The observation to data transmission mode occurs when the UTE no longer has onboard memory resources for storing the observation data. This transition can occur even when the BPME does not show any sign of energy depletion and the light intensity from the genetically modified bioluminescent organisms is increased. The data transmission mode to observation mode occurs after the UTE has completed the transfer of data and has enough memory resources to store data arising from the observation process. In this case, the BPME has sufficient power capacity to support the execution of the concerned transition. The flowchart showing the execution of the mode transition is shown in Figure 4.

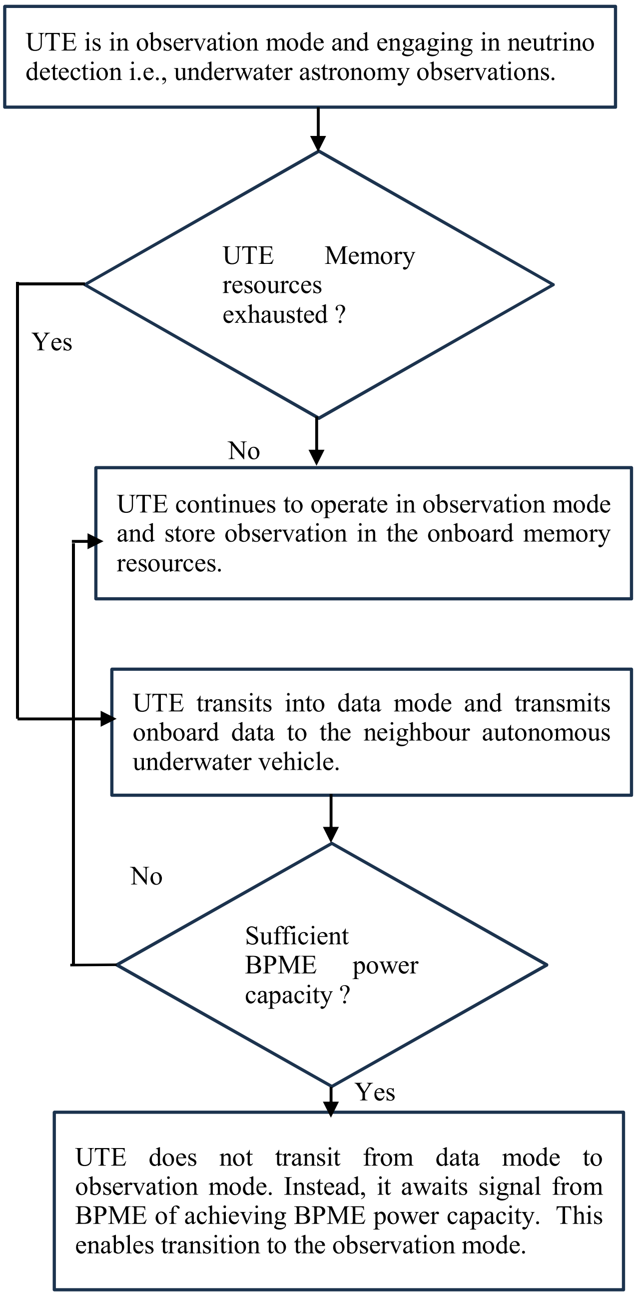

Figure 4: Flowchart showing the transition from the data transition mode to observation mode in the proposed UTE.

I. PERFORMANCE FORMULATION

The discussion in this section formulates the performance metric i.e., the angular resolution. The angular resolution is formulated for two cases. The first case and second case are the existing case, and proposed case, respectively. The angular resolution for the existing case and proposed case are denoted Γ_1, and Γ_2, respectively. The formulated angular resolution given the wavelength associated with neutrino observations, $\lambda_{neutrino}$, initial baseline, l_1 increased by $\alpha_1, 0 < \alpha_1 < 1$ is:

$$\Gamma_1 = \frac{\lambda_{neutrino}}{l_1(1 + \alpha_1)} \tag{2}$$

In addition, the use of the existing approach enables the realization of an increase in the separation between underwater telescopes. An increase in this manner considers that the underwater telescopes are deployed over multiple clusters. In each of these clusters, the underwater telescopes engage in independent underwater astronomy observations. For the case of multiple clusters, the initial baseline, l_1 increased by $\alpha_1, 0 < \alpha_1 < 1$ are now presented for the a^{th} cluster as $l_1\ (a)$ and $0 < \alpha_1(a) < 1$, respectively. Therefore, the overall angular resolution for multiple clusters Γ_1' is:

$$\Gamma_1' = \sum_{a=1}^{A} \frac{\lambda_{neutrino}(a)}{l_1(a)(1 + \alpha_1(a))} \tag{3}$$

Furthermore, the use of the proposed approach with support for underwater telescope ubiquity also supports the realization of increased underwater telescope baseline. In this case, the initial baseline denoted as α_1 is increased by a multiple denoted as β. In this case, the increase in the baseline is significant. The angular resolution in the proposed case Γ_2 is given as:

$$\Gamma_2 = \frac{\lambda_{neutrino}}{l_1(1 + \beta\alpha_1)} \tag{4}$$

In addition, the use of the proposed approach can also enable an increase in the baseline. The deployment of the proposed approach leads to the case where $\beta\alpha_1$ in (4) is re-written as $\beta_1(a)\alpha_1(a)$ for the a^{th} cluster. In this case, the overall angular resolution for multiple clusters Γ_2' is :

$$\Gamma_2' = \sum_{a=1}^{A} \frac{\lambda_{neutrino}(a)}{l_1(a)(1 + \beta_1(a)\alpha_1(a))} \tag{5}$$

Where $\beta, \beta > 1$ is the increment ratio in the baseline associated with the use of the BPME, UTEP, and UTE.

II. PERFORMANCE EVALUATION

The performance evaluation results obtained via simulation are presented in this section. The simulation parameters are presented in Table I. The simulation scenario presented in Table I is one comprising 15 underwater telescopes and observing neutrino radiation at the millimeter wavelength of 1.2mm. The choice of the wavelength has been motivated by the discussion in [22] where it is observed that neutrinos have wavelength in the order of millimeters.

In the simulation, the use of the proposed approach enables a significant increase in the baseline. Furthermore, the simulation scenario considers that the underwater telescope has access to power from the light enclosure and is closely placed to the light enclosure. Hence, the role of the water absorption of the light from the light enclosure is minimal in this case.

The baseline in this case is increased in a ratio i.e., a multiple of the separating telescope distance. Furthermore, MATLAB simulations show that the consideration of a multi-wavelength underwater astronomy observation objective does not influence the improvement in the angular resolution.

In the considered scenario, the underwater telescopes are integrated into a network that enables the transfer of acquired observational data.

Examples of proposed network architecture that achieve this goal are in [23–24].

In addition, the performance evaluation considers that neutrino observation focuses on a single radiation wavelength. In this case, the observation wavelength is in the order of millimeters with a value of 1.2mm as indicated in [22]. The non–consideration of multi-wavelength neutrino observation has been done to ensure a focus on performance benefit of the proposed approach. The use of the proposed approach focuses on enhancing the angular resolution by increasing the baseline. Its focus is not on defining the science objective associated with the conduct of underwater astronomy observation that focuses on the observation wavelength.

The results of the angular resolution for the different values of the increment in the baseline ($\alpha_1(a)$) and the ratio of the increase in the baseline i.e., $\beta_1(a)$ is in Figure 5. The results for the percentage improvement in the angular resolution given different values of $\beta_1(a)$ is in Figure 6. In addition, the results of the percentage improvement in the angular resolution considering the varying increments in the baseline for different values of $\beta_1(a)$ is presented in Figure 7. The result in Figure 5 considers the case where $\beta_1(a)$ has a value of 6.5. The results in Figures 6 and 7 consider the case where there is an increment in the value of $\beta_1(a)$ from 6.5 to 7.0, and 7.5. This increment implies a significant increase in the underwater telescope baseline.

The presented results in Figure 5 show that an increase in the baseline improves the angular resolution. A lower angular resolution is better than a higher angular resolution. Analysis shows that the use of the proposed approach given that $\alpha_1 = 0.20$, $\beta = 6.5$ instead of the existing approach with $\alpha_1 = 0.20$ enhances the angular resolution by an average of 47.8%. The use of the proposed approach given that $\alpha_1 = 0.20$, $\beta = 6.5$ instead of the existing approach with $\alpha_1 = 0.50$ enhances the angular resolution by an average of 34.8%.

Furthermore, the results in Figure 6 shows that an increase in the value of β enhances the angular resolution. In this case, the presented results show that angular resolution improvement is enhanced with an increasing value of β.

Table I: SIMULATION PARAMETERS

S/N	Parameter	Value
1	Number of underwater astronomy observation clusters.	15
2	Neutrino observation wavelength (mm)	1.2
3	Minimum increment proportion of separating distance (%)	20
4	Mean increment proportion of separating distance (%)	35
5	Maximum increment ratio of separating distance due to BPME incorporation	6.5

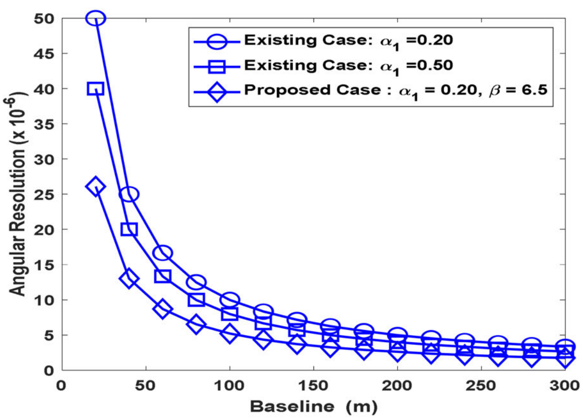

Figure 5: Angular resolution in the proposed case $\alpha_1 = 0.20$, $\beta = 6.5$, and the existing cases given that $\alpha_1 = 0.20$ and $\alpha_1 = 0.50$

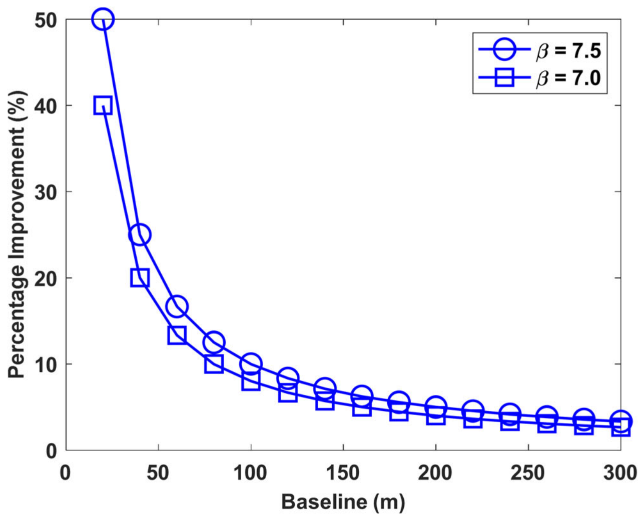

Figure 6: Improvement in the Angular resolution in the proposed case when $\beta = 7.0$, and $\beta = 7.5$.

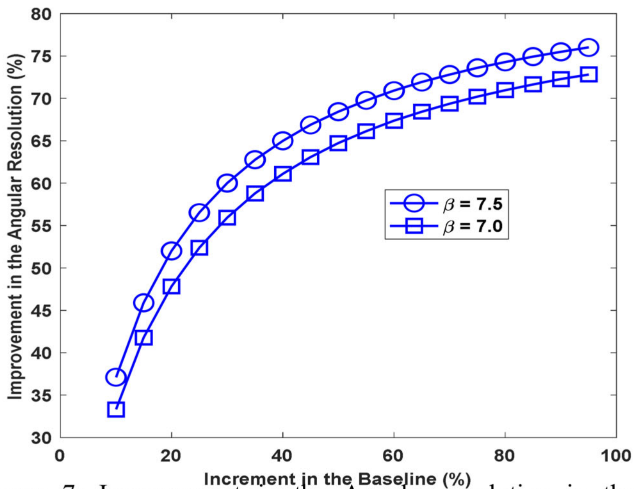

Figure 7: Improvement in the Angular resolution in the proposed case when $\beta = 7.0$, and $\beta = 7.5$ considering an increase in the baseline at varying levels.

The results in Figures 5, 6, and 7 consider the case where the role of water absorption on the light output from the light enclosure is minimal. This results in a case where the underwater telescope has access to power. In the case where the water absorption becomes significant, the underwater telescope does not receive sufficient power to participate in underwater astronomy. This is because of the reduced light intensity that is incident on the light interception entity (underwater solar panel) from the light enclosure. The occurrence of this effect leads to a case of non–functional underwater telescopes. This is considered in the simulation via the consideration of the parameter associated with the proportion of functional telescopes. Furthermore, the occurrence of non – functional underwater telescopes result in a reduction in the baseline. A reduction in the baseline leads to a degradation in the angular resolution. In this case, the results of the angular resolution previously presented in Figure 5 are shown considering the occurrence of water absorption in Figure 8. For the results in Figure 8, the minimum functional ratio, mean functional ratio, and maximum functional ratio are 1.27%, 18.9%, and 38.3%, respectively. The functional ratio implies that at least 1.27% and at most 38.3% of the underwater telescopes in the scenario associated with Figure 5 are functional. The use of the proposed solution instead of the existing approach enhances the angular resolution by an average of (57.2–78.6)%. This shows that the use of the proposed approach enhances angular resolution most when there is an occurrence of some non– functional telescopes. [1]

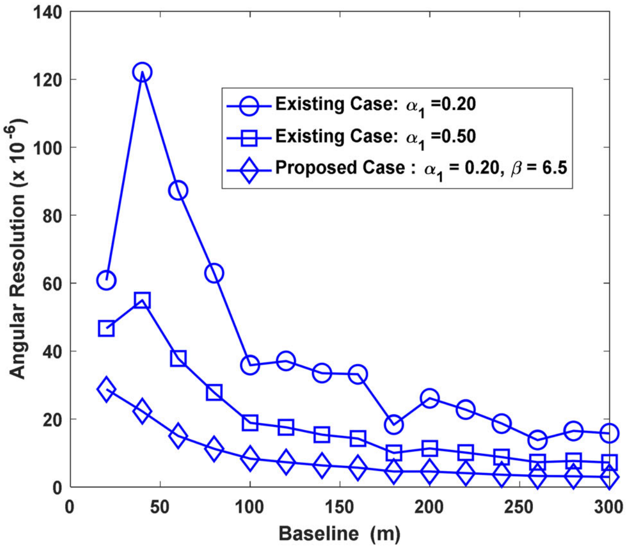

Figure 8: Angular resolution in the proposed case $\alpha_1 = 0.20$, $\beta = 6.5$, and the existing cases given that $\alpha_1 = 0.20$ and $\alpha_1 = 0.50$ considering the occurrence of non-functional telescopes.

I. CONCLUSION

The discussion in the paper presents a novel system motivated by array capacity in communication systems. The novel system uses insights from communication systems to design a wave interception model for power generation. The wave interception model is motivated by bioluminescence and provides energy output intended for use by underwater telescopes. The proposed approach advocates the integration of underwater telescopes into the bioluminescence derived energy source. The integration enables the realization of ubiquitous underwater astronomy with improved angular resolution. The use of the proposed integration model enhances the angular resolution. The angular resolution is enhanced by an average of (34.8 – 47.8) %.

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