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Fuzzy logic, edge enabled underwater video surveillance through partially wireless optical communication.

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Fuzzy Logic, Edge Enabled Underwater Video Surveillance Through Partially Wireless Optical Communication

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Abstract

The Underwater Internet of Things (UIoT) represents an area of research that holds significant interest among scientific, defence, and industrial communities. The automation of subsea applications is a key focus to safeguard assets in this domain. Visible Light Communications (VLC) shows promise in overcoming the constraints inherent in acoustics, particularly in specific environmental conditions. This project proposes the implementation of a Software Defined Network (SDN) capable of wirelessly transmitting video from source to sink, irrespective of local conditions. This is achieved by incorporating a wired optical connection between the source nodes located on the seafloor, thus providing an additional communication option. This wired connection enables the nodes to bypass obstacles such as suspended particulate matter, objects, or excessive ambient noise in the water, which obstruct VLC communications, and instead transmit the data from an alternate location. To determine whether wireless transmission is viable, a fuzzy logic controller/edge routing system assesses the environmental conditions and based on the collected data, selects the most suitable route. Through MATLAB modelling, it has been demonstrated that this SDN has the potential to reliably transmit video and other forms of data while minimizing energy consumption by eliminating the need for an acoustic communication link.

Keywords: Wireless Optical Communication, Subsea Surveillance, Underwater Wireless Sensor Networks (UWSN), Structures in the Marine Environment, Fuzzy Logic, Routing Protocols

1. Introduction

Wireless communication allows the transmission of real-time data from underwater sensors, cameras, and other devices to the surface or a remote location. This capability is critical for monitoring and carrying out various underwater activities that require timely data analysis and decision-making. From the perspective of security, it could be acoustic data to monitor for illicit submarine activity used in drug smuggling from subsea microphones or, in future, visual surveillance to protect critical infrastructure such as pipelines and communication cables. While there are challenges to underwater wireless communication, such as limited bandwidth, propagation issues, and the impact of water absorption on signal range, ongoing research and technological advancements are continually improving the reliability and capabilities of subsea wireless communication systems. Typically, remote observations of subsea data take place using acoustic channels that are incapable of carrying video transmissions over large distances due to low propagation speed and fading channel properties. Combined with excessive energy demands, the transmission of data through these networks are also infrequent, as the cost of retrieval for recharge is large, excessive utilisation results in short lifespans and thus frequent recharges. This renders the technology prohibitive for pervasive use in the form of an equivalent Internet of Things (IoT), particularly for applications such as visual or audio surveillance as the is incapable of meeting the demands of high-definition video or audio physically. A possible solution for high data rate underwater wireless communication technology is the utilisation of VLC technology. This technology has the capability to signal for applications beyond what acoustics can achieve on a physical level. The available bandwidth is significantly wider than the acoustic network equivalent, energy demands are significantly reduced for equivalent applications, and the propagation time is magnitudes smaller, given that light in this environment propagates at around 66% of speed of light, whereas acoustic waves propagate at around 1500 m/s. These characteristics render it a suitable candidate for underwater video links. However, several of these gains are conditional and dependent on the environment [1]. Major environmental contributors to the failure of a VLC signal being received are the turbidity of the water due to presence of particulate, the ambient noise level and the blockage of Line of Sight (LOS) links, thus it is important to manage the transmission in accordance with these variables. Table I visualises and compares the characteristics of each signalling methodology.

The researchers engaged in this field are currently engaged in developing either of these two technologies or developing a multimodal network that uses both. The multimodal communities suggest using each technology to their respective strengths so that a network capable of meeting the threshold of being reliable, energy efficient yet capable of low propagation delay and high bandwidth data transmission, however, it still relies on the acoustic architecture to achieve this. This is made achievable using edge routing and SDN technology paradigms that are also ongoing research areas. We propose a new SDN and edge routing technique that aims to circumvent the need for the acoustic link by using wireless VLC and an optical fibre network to achieve robust communication from source to sink in shallow, Jerlov Type II waters, Type II corresponding with coastal water where there is a presence of organic matter from nearby land [2]. This network will use a fuzzy logic system to sense the channel's conditions and make decisions whether to forward packets using wireless VLC or "pass" the packet to another seafloor source node through optical fibre where the conditions are more likely to allow for a wireless VLC transmission. This SDN is simulated by utilising robust modelling in MATLAB, analysing VLC channel behaviour to optimally position relay nodes, developing a fuzzy logic controller to decide which communication method to use and a routing protocol that will route the packet through the wireless network according to the local conditions in the environment. Based on this a theoretical network will be proposed that has the parameters necessary for transmitting surveillance video robustly.

Table 1 VLC and acoustic signal parameters [3]

Characteristic	VLC	Acoustics
Bandwidth	<150Mhz	<100kHz
Line-of-Sight	Yes	No
Data rate	<Gb/s	Kb/s
Latency	Low	High
Range	<150m	<10km
Transmission Power	Watts	Tens of Watts
Speed	2.255×10^8m/s	1500m/s

II. Background

Multimodal communication [4], edge routing [5] and SDN [6] are emerging paradigms in networking that have significant potential for utilisation in future networking. SDN technology is the abstraction of the control element in a traditional network inherent in routers and switches into a novel software layer that manages the flow of traffic from source to sink separately from the hardware technology that is responsible for transmitting the data itself. This layer is centralised on a processing unit that makes decisions based on network parameters as to how the data should flow through the network. This technology shows potential within Underwater Wireless Sensor Networks (UWSN) as software control is significantly more flexible than hardware equivalents from several aspects [7]. For example, the network administrator can monitor the performance of the underwater network remotely and identify problems with energy consumption, reliability, etc. Using an SDN, the network parameters can be reconfigured to remedy these issues, this is particularly prominent within UWSN as network performance is critical to maintain lifespan and use bandwidth efficiently as what constitutes good network performance can change rapidly in this unpredictable environment, particularly concerning wireless VLC communication.

Edge routing is sub-topic within edge computing, the paradigm that aims to locate computing assets from a centralised position to the "edge" of the network, this being the point proximally close to where the data is being sourced from, in this case the nodes positioned on the seafloor [5]. Taking the processing aspect closer to the network edge has potential to achieve several benefits in the UWSN. This could include the ability to compress the collected multimedia data from sensors before it is transmitted, resulting in energy efficiency gains as a result from transmitting less data, thus, increasing the lifespan of such a network as well as reducing latency resulting in reduced end-to-end delay. In edge routing, the routing decisions are also localised proximally to the source, this is specifically useful for wireless VLC communication underwater as this shift allows for quick routing responses to unpredictable conditions, given that sea life, detritus and sediment can interfere with the LOS link of a transmitting node whimsically, a localised edge-routing methodology can quickly adapt to this interference and route around the obstacle.

Multimodal communication is an emerging paradigm where a network can manage multiple forms of networking [8]. In the underwater environment, optical and acoustic communication are the technologies most likely to be considered, however, there is a broad range of topologies and concepts on how best to utilise them. Junior C. et al. presented a topology and routing algorithm that utilises nodes equipped with both acoustic and VLC technologies within clustered network to orderly transmit information from source to sink [9]. Hu, T. et al presented a methodology and routing technique where the networks were arranged by clusters, however, only the head of each cluster (the node that has been designated decision maker for the cluster) was permitted to communicate via acoustics [10]. A key contention with these proposals is the reliance on acoustic technology which by nature, requires a significant amount of power to transmit packets and will diminish the network lifespan if not balanced carefully.

Subsea video transmission has also been discussed in the academic literature. Some have focussed on compressing data to the point where it can be successfully transmitted through the limited bandwidth of an acoustic channel using various compression algorithms. Campagnaro, F. et al. presented an investigation into such techniques finding that low data rate video was achievable with the caveat, however, of being in monochrome and without detail because of the edge detecting algorithms used [11]. Han, S. et al. discusses an investigation where a low-quality video was transmitted using a commercially available EvoLogics HS whilst comparing CODEC algorithms [12]. Regarding wireless VLC communication, Doniec, M. presented a successful investigation into transmitting video through an optical channel at 4 Mb/sec which is sufficient for transferring high quality video if the quality of service is sustainable, orders more so, that what is achievable using the acoustic modems covered [13].

III. Network Design for a Case Study

A case study has been provided to illustrate a potential implementation for this network. Pipelines and long-distance network cable runs can be commonly found in shallow waters and could be an asset worth monitoring. Shallow, coastal waters typically follow the characteristics of Jerlov Type II as the concentration of suspended organic particulate is high compared to that of clear oceanic waters. Generally, the levels of this particulate decreases as depth increases. Based on these water characteristics and theories regarding wireless VLC networking, nodes can be placed in such a way that robust transmission of video can take place from seafloor to surface with a well-designed network. As such there are three fundamental proposals here that have been considered necessary to achieve this network topology. The first being the topology which is illustrated in fig 1.

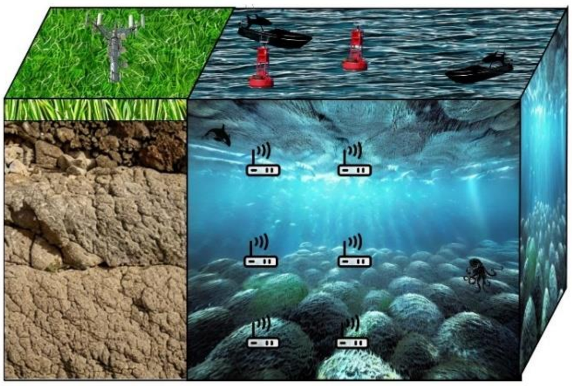

Fig. 1 An illustration of an abstract multi-hop network topology

In order to simulate the wireless VLC channel, the Bit Error Ratio (BER) is calculated for a variety of extinction coefficients to understand how the response changes when the water conditions do, for LOS links. Given that there is a wavelength component to the behaviour that changes with factors such as salinity and the presence of biological detritus, this will allow for exploration as to which wavelength should be utilised in addition to what distance the nodes should be placed. The power level of the signal reaching the receiver through the medium, denoted as P_R, is determined using formula 1 [14].

$$P_R = P_T \eta_T \eta_R L_{pr} \left(\lambda, \frac{d}{\cos \theta}\right) \frac{A_{Rec} \cos\theta}{2\pi d^2 (1-\cos\theta_0)} \quad (1)$$

Where P_T is the transmission power, η_T and η_R are optical efficiencies of the transceiver and receiver respectively, $L_{pr,}$ the propagation loss factor as a function of wavelength, λ, and distance d is given by formula 2.

$$L_{pr} (\lambda, d) = e^{(-c(\lambda)d)} \quad (2)$$

Where distance, d, is that which is between the transmitter and receiver plane, θ is the angle between the perpendicular to receiver plane and the transmitter. A_{Rec} is the receiver aperture area and θ_0 is the laser beam divergence angle. Fig.2 illustrates how these parameters relate to each other.

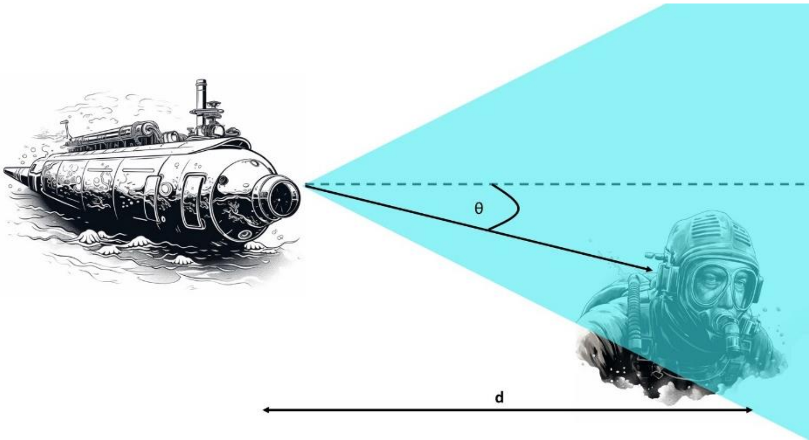

Fig. 2 An illustration of what d and ϕ are in the context of formula 1 and 2.

Stochastic modelling for coherent photon arrival in photon counters can be used to understand the BER in this channel. It is a Poisson distribution, where the photon arrival rate during the gated receiver slot, T, is given by formula 3 [14].

$$r_S = \frac{1}{T}\left(\frac{P_R}{R_D}\right)\frac{\eta_D}{h_v} \tag{3}$$

Where R_D is the data rate, η_D is the detector counting efficiency, P_R is the output from formula 1, h is Planck's constant and v is the frequency of the photon. Formula 4 shows the method utilised to determine the BER(γ) , where $r_1 = r_d + r_{bg} + r_s$, $r_2 = r_d + r_{bg}$, r_d is the background counting rate and r_{bg} is the background counting rate and the complementary error function *"erfc"* is given by formula 5 [15].

$$BER\ (\gamma) = \frac{1}{2}\ erfc\{\frac{r_1T - r_0T}{\sqrt{2}(\sqrt{r_1T}+\sqrt{r_0T})}\} \tag{4}$$

$$erfc(\psi) = \frac{2}{\sqrt{\pi}}\int_{\psi}^{\infty} \exp(-\gamma)\, d\gamma \tag{5}$$

Once the BER(γ) has been obtained, the SDR of a given packet size in bytes can be given by formula 6 where m is the size of the packet in bits for either of the architectures.

$$p_{successful}^{m}(\gamma) = [1 - BER(\gamma)]^m \tag{6}$$

In addition to these calculations SNR was obtained using formula 7 [16].

$$\gamma = \frac{P_{R\,LOS}\, S}{2h(I_d + P_{R\,LOS}\, S)\, B + \frac{4KTB}{R} + N_A^2} \tag{7}$$

Where S is the sensitivity, h is Planck's constant, I_d is the dark current, B is bandwidth, K is Boltzmann's constant, T is temperature and N_A is the ambient noise given by $N_A = E0A_RS$ where E_0 is the scalar downwelling solar irradiance. Formula 7 considers dark currents, thermal and ambient noises in the process of receiving transmissions. To calculate the energy consumed by the network in transmitting and receiving packets for a given path, E_T, based on the simulation parameters in this scenario, knowing the power consumed in watts of the transmitters and receivers, the size of the packets and the data rate we can use the formula8, where N is the number of nodes in the route, P_T and P_R is the energy consumed in transmitting and receiving data respectively.

$$E_T\ = \sum_{0}^{N-1}(P_T + P_R) \tag{8}$$

To calculate the end-to-end delay D_{E2E}, the formula 9 was applied.

$$D_{E2E}\ = D_{PROC} + D_{PROP} + D_{TRANS} \tag{9}$$

Where D_{PROC}, D_{PROP} and D_{TRANS}, are the delays from processing, propagation and transmission respectively. This modelling in this case study refers to the data found in the DESERT simulator [17] that was gathered on a North Atlantic Treaty Organisation research cruise in the Mediterranean Sea that represents column of water that contains a graded transition from clear oceanic water to type II coastal as depth decreases . This data contains temperature, solar irradiance, extinction coefficients according to depth. This model specifically uses the dataset from [17] titled CTD25 as the example in this paper. For wireless VLC communication to function in any body of water of depth, the propagation range becomes a limiting factor, partially the reason why it is a challenge to record video underwater, light is limited depending on the properties of the water thus, it becomes hard to perceive more than tens of meters. In addition, characteristics are not uniform between water types; thus, the design of the network will change according to the range of the cameras in that water. To therefore, achieve a level of coverage over an area, the camera sensors would need to be placed so that coverage is attained as desired. Having knowledge of the propagation characteristics of light in this instance would help solve for camera placement. Fig. 3 shows the extinction coefficients in Type II Jerlov water for wavelengths in the visible light range, where *a*, *b* and *c* are the absorption, scattering and extinction coefficients respectively.

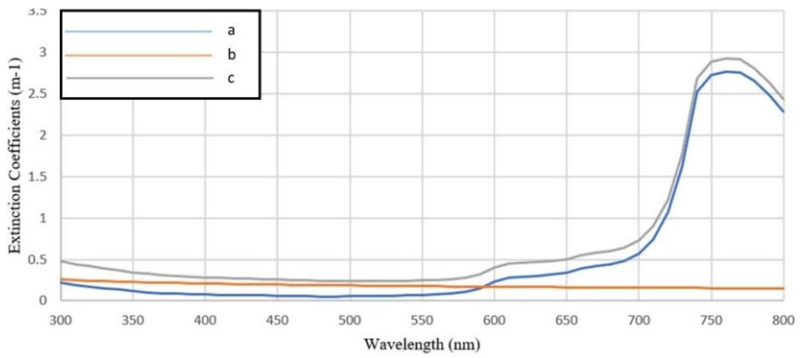

Fig 3. Extinction coefficients of type 2 wasters at visible light wavelengths where a, b and c are the absorption, scattering and extinction coefficients respectively.

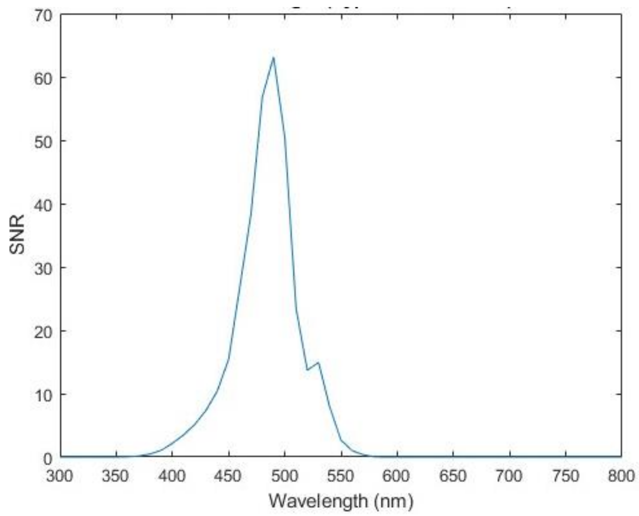

Fig 4. The SNR at 200 m distance from source in clear oceanic water.

As can be seen, in type II waters similar rules apply to what is commonly understood for coastal waters regarding that bandwidth in red and orange wavelengths are disproportionately attenuated in these waters, the minima tend towards green-yellow wavelengths. However, the property of the water is not constant throughout the water column, although the water itself can be described as type II at the surface, with an extinction coefficient of around 0.300, it can be seen from the data that the coefficient decreases towards 0 with depth increase until about 125m deep where it becomes negligible [14]. The data in fig 4 suggests that if water remains constantly clear a camera could potentially visualise up to 100m of distance with the correct lighting arrangement, this would be blue-green light in waters that are clear [1]. Therefore, the network could be designed to accommodate a camera every 100m or so to achieve coverage needed as the photons from the light need to complete a round trip back to the camera sensor as they reflect off any objects in range.

Similar modelling can be applied to calculate how many nodes are needed to reach the surface from the pipeline located at the given depth in water. The difference is, however, that the photons do not need to complete a round trip in the communication of packets from source to sink, thus, full range can be taken for deciding where to place the nodes. In fig. 5 (left), the Successful Delivery Ratio (SDR) for several extinction coefficients in different Jerlov Water Types is given, along with the extinction coefficient of light in water around 125m deep in fig. 5 (right). The results show how range increases for different transmission powers in the deepest waters where the extinction coefficient is lowest.

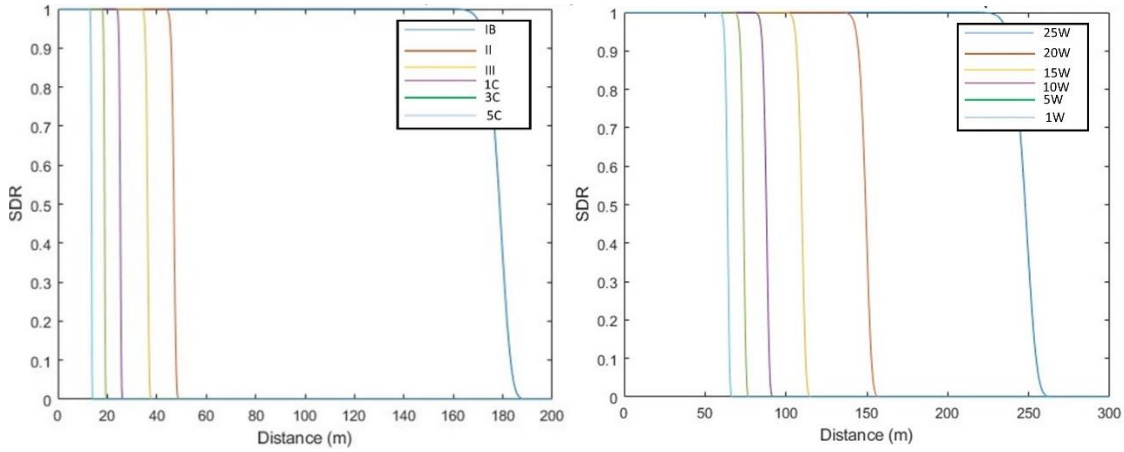

Fig 5. (left) The SDR over distance in different Jerlov Water Types, **(right)** The SDR over distance for different transmission powers.

As can be seen, when the emission occurs at depth, where the volume of suspended organic particulate has diminished, the range has increased consequently, however, as the VLC signal travels up the water column, the signal will be attenuated by the particulate and thus, there will be a point where the signal will require repeating to sustain it above the noise floor caused by ambient light and dark current. By modelling how the power behaves over the distance from source to sink. Fig 6. shows an example of how the extinction coefficient and noise level shifts as light propagates towards the surface, Fig 7. displays the results of calculating SNR in relation to distance from this graph.

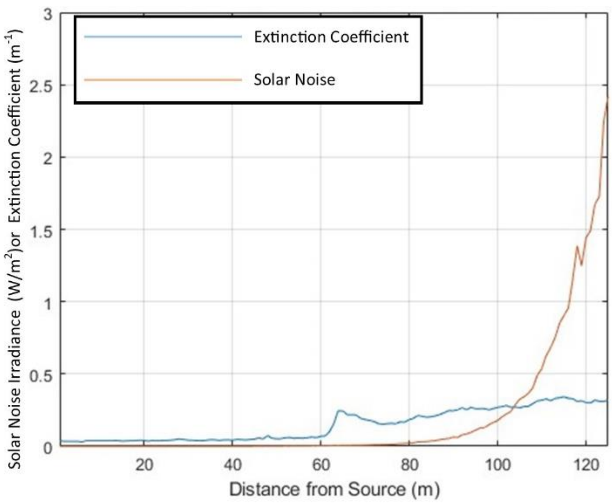

Fig 6. Solar noise and the extinction coefficient increase as distance from surface decreases.

As the distance from the transceiver increases the SNR decreases until the point where it drops through the noise floor. As can be seen in fig. 8 if these theories are followed through then around 100m range is achievable through this initial link, from there however, the extinction coefficient and noise through sunlight increases, at this point it becomes necessary to repeat the signal so that it reaches the surface, this could be through a photodiode node that is directly wired to the sink or a wireless node with a transmitter that has enough power to transmit to that link. Based on this data, the placement of nodes can be decided as to where would be best to relay the data from source to sink. Fig 9 shows this network.

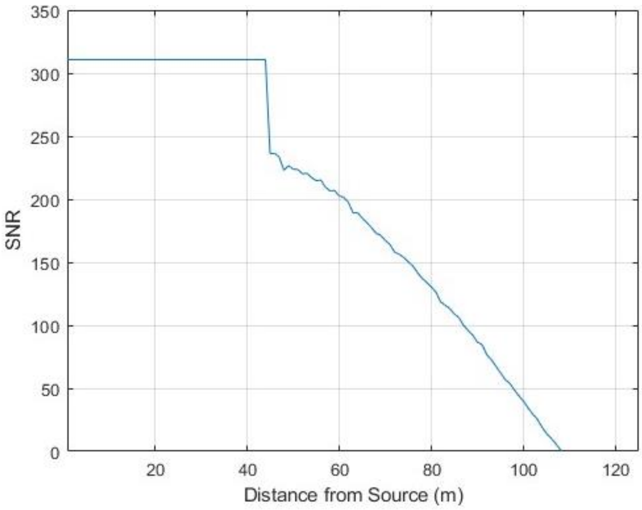

Fig 7. The relationship between SNR and upwards distance from source.

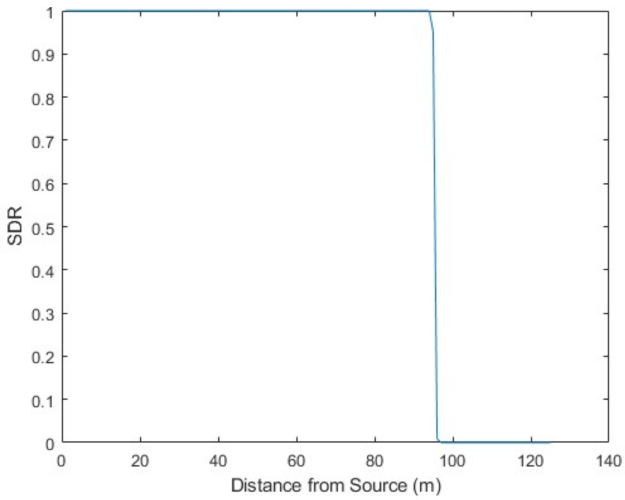

Fig 8. The SDR relationship given this information using photon counting.

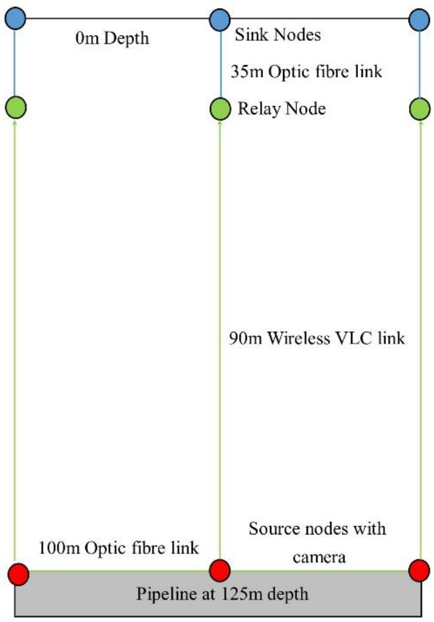

Fig 9. An abstract illustration of part of the proposed network where red circles are the source nodes, green are the relay nodes and blue are the sink nodes.

Given this paradigm, there needs to be two further novel mechanisms to effectively make use of this network. A system capable of making reasonable decisions based on sensor data whether to make use of the wireless link or attempt to defer to another point in the network with more favourable conditions for wireless VLC transmission, this is shown in fig 10. (left). If the latter is decided, a routing methodology must be utilised that can route the packet to the node that is most likely to result in successful transmission of the packet. Fig 10. (right) shows a flow chart of the proposed routing algorithm.

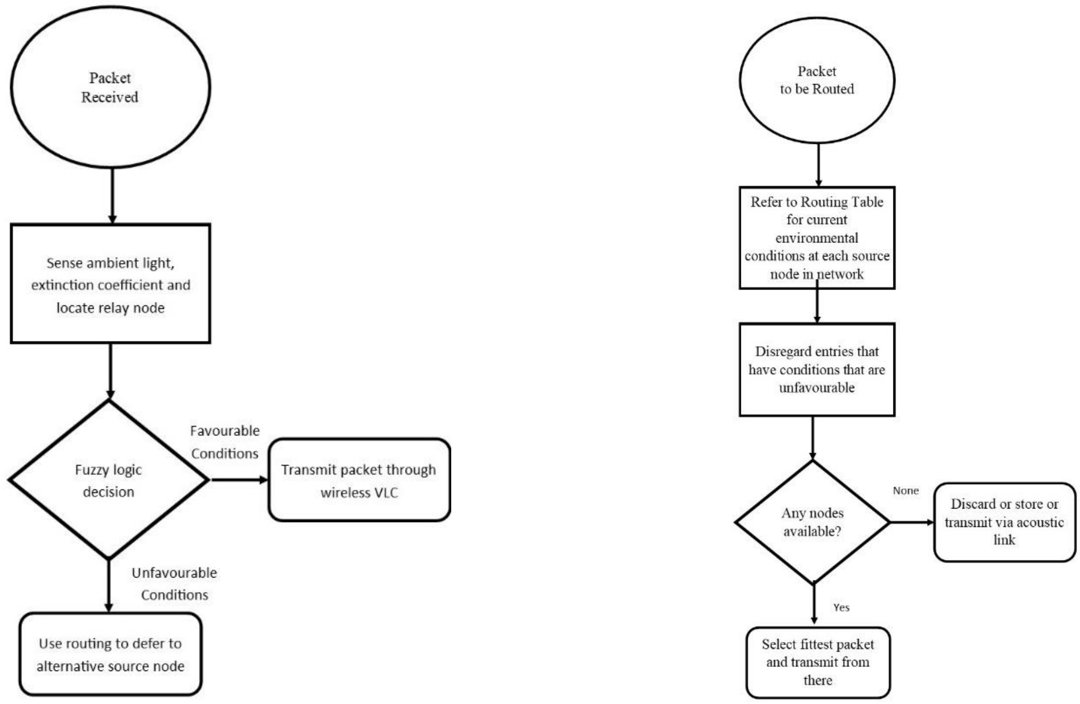

Fig 10. (left) The proposed fuzzy logic system flowchart. **(right)** The proposed source routing algorithm flowchart.

The fuzzy logic system will be connected to a series of sensors to determine if the local area is free from interfering sources of noise, detritus clouds and sea-life by measuring the local ambient noise, extinction coefficient changes driven by floating particulate and whether it can "see" the relay node's beacon of light. If all three criteria are met, then the node can proceed with wireless VLC transmission. However, if one of those criteria is not met, the likelihood is significant that the video will reach that relay node is dubious, thus, for the sake of robust transmission, it shall be deferred to an alternate source node with improved local conditions.

The routing protocol responsible for this assumes that a wired connection is available that allows for source nodes along the asset to communicate with one another, it uses this connection to develop a "routing table" of each node's local environmental conditions that is updated before a transmission of video, each node manages its own table then shares it with its neighbours periodically. Based on this routing table, the node will disregard deferring the transmission to a node that does not meet the environmental criteria essential for successful transmission, then for those nodes that remain candidates, the sensor values will be scaled from 0 to 1 and shall be summed together for the algorithm to decide which one is "fittest" for transmission, lowest scoring node will correspond with the one with the lowest combined extinction coefficient, ambient noise level and the highest level of certainty in classifying the relay node's beacon. From there, that node will transmit the packet, if no candidates are available then the network will discard the packet or it can store it in local memory if later transmission is acceptable within the contexts of this network , this is justifiable as a video stream can tolerate some packet losses, however, as long there are a significant number of nodes available in the network over a wide enough area then the chances are there will be one node capable of carrying the transmission on.

Based on these three technologies, MATLAB can be used to analyse the performance of the network and provide insight into how the network will perform when carrying video.

IV. Results and Discussion

The simulation assumes the following values shown in table 2 for the variables.

Table 2. A table of simulation constants and variable simulation parameters

Parameter	Value
Depth	125m
Data Packet Size	500 bytes
WVLC Propagation Rate	225,000 km/sec
WVLC Wavelength	532nm
WVLC Extinction Rate	Measurement
WVLC Efficiencies of Transmitter and Receiver	0.9
Pulse Duration	1ns
Transmitter Inclination Angle	0 °
Beam Divergence	68°
Detector Counting Efficiency	16%
Dark Counting Rate	1MHz
Background Counting Rate	Measurement
Receiver Aperture Area	$0.01m^2$
WVLC Data rate	5Mb/sec
WVLC Transmission Power	20W
WVLC Receiver Power	10W
Optical Fibre Data Rate	1GB/sec
Optical Fibre Transmission Power	Negligible
Optical Fibre Propagation Rate	210,000km/sec
Node Processing Time	1ms
Time of Day	Noon

Observing the modelling carried out in section III, in the ideal scenario as seen in fig 11. (left), the link is projected to have a successful delivery ratio of 100% up until 98m from the source. Thus, this 90m is projected to be sufficient to transmit this 500-byte packet at a data rate of 5MB/sec. If we are to consider the case where the packet is elected to be transmitted by wireless VLC to the sink node via the simplest route possible, as illustrated in fig 11. (left) the results of propagation time, energy consumed are shown below in table 3.

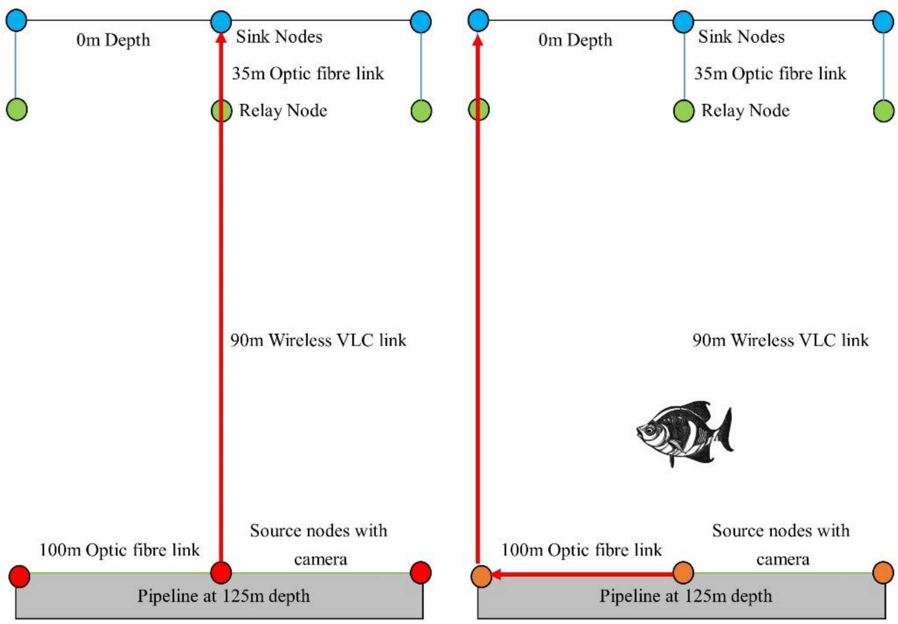

Fig 11. (left) An abstract illustration of the network route based upon the initial modelling and there is no LOS obstruction, **fig 11. (right)** The same except an obstruction has occurred causing the system to route around the object.

Table 3. The results of the network modelling, showing the resulting network performance parameters

Parameter	Value
End-to-End Delay	2.804ms
Power Consumed	24mJ

As can be seen the energy taken to transmit this packet is low and achieves a fast transmission from the source to the sink in first instance. Now, consider the case in fig 11 (right) where the local conditions have worsened significantly, this could be because a fish is in the way of the LOS link or a local ROV has raised sediment from the seabed, thus it cannot detect the beacon from the relay node, the processing system has sensed this. A Monte Carlo simulation was used to characterise the system, and thus, find the point where the links become likely to diminish given the circumstances and guide the design of the fuzzy logic system stage, in this instance change of ambient count rate can be used to describe a scenario where bioluminescence or an ROV interferes with the signal and a change in extinction coefficient can be seen as being akin to the scattering or absorption coefficient increasing due to particulate or organic matter interfering with the LOS. When it comes to classifying for the beacon to decide if objects in the way, 80%-100% certainty are common values used in image classification, this can be used as a metric for the image identification aspect of the fuzzy logic system.

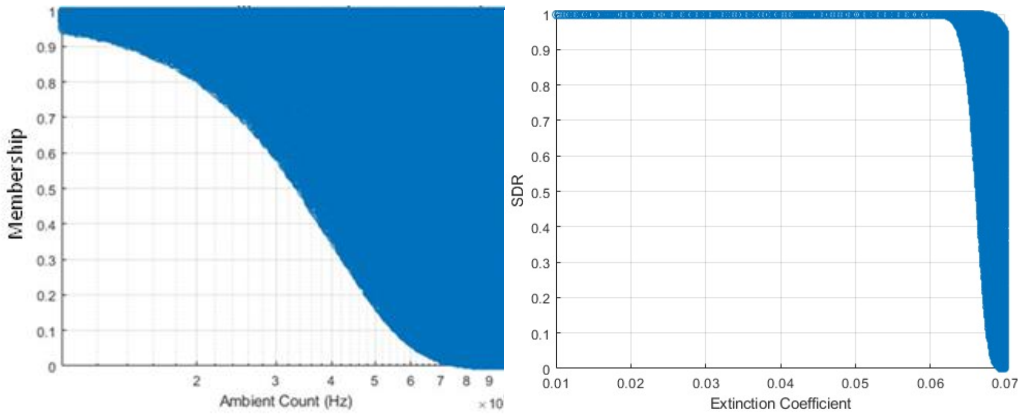

Fig 12. (left) The results of Monte-Carlo modelling between 0.03 and 0.07 extinction coefficients to produce a distribution of SDR values for ambient count rates and thus, the fuzzy set for Background Count (Bkcnt) **Fig 12. (right)** The converse, where ambient count rate was varied between 1Ghz and 10Ghz to understand how it effects the relationship between extinction coefficient and SDR and thus, the fuzzy set for Extinction Coefficient (ExCo).

Based on this data the input memberships can be plotted, these can be seen in fig.13 (left) and (right).

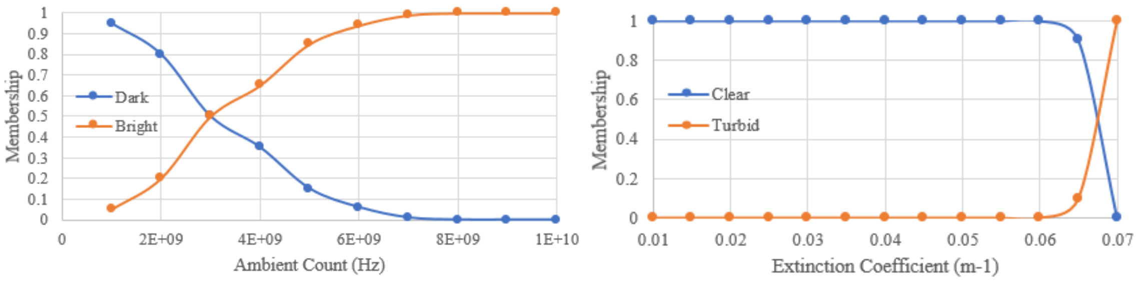

Fig 13. (left) The input membership for Background Count based upon the data in fig 12. (left) **Fig 13. (right)** The input membership for Extinction Coefficient based upon the data in fig 12 (right)

Based on this, the output membership can also be applied using fig. 8 as we know specifically the range that can attained given normal water conditions in the dataset and that deviations beyond this leads to increasing uncertainty, this point can be used as to where the switch between wired and wireless communication is carried out.

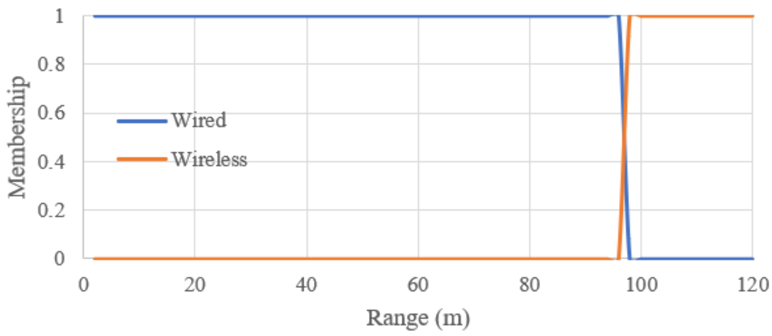

Fig 14. The output membership for Communication Method based upon the data in fig 8.

Based on these inputs the fuzzy rule system in Table 4 was utilised to make the correct decisions for this scenario, effectively carrying out the algorithm laid out in fig 10 (left). The Mamdani inference method was utilised as it is relatively computationally simple to save energy, simple to update from over the network due to its simplicity to adjust performance and robust to uncertainty which is a significant problem within an unpredictable environment such as that underwater. The formulae for fuzzification and defuzzification in the Mamdani method are given in equations 10 and 11 respectively [18].

$$\mu_r(x, y) = MIN\{\mu_A(x), \mu_B(x)\} \qquad (10)$$

$$Z_{COA} = \frac{\int_Z^Z \mu_A(Z)\, Zdz}{\int_Z^Z \mu_A(Z) dz} \qquad (11)$$

In formula 10 μ is a given membership function, x is the input being evaluated for the degree of membership in A or B and μ_r (x,y) is the given degree of membership for the point x,y for the fuzzy set r. For formula 11, Z_{COA} represents the Center of Area (COA) for variable Z which represents a value within the range of interest, $\mu A(Z)$ This is the membership function of the fuzzy set A with respect to the variable Z. The COA is a concept used to determine a representative value for a fuzzy set that characterizes its "center" or "average" position within a certain range.

In the case of this scenario, the uncertainty value you would shift and elect to shift to wired communication, in other cases the system would switch if the ambient count reached above 1Ghz or if the extinction coefficient rose above 0.07. From there, the routing protocol shown in fig 10. (right) makes decisions as to which node should be used to carry on the transmission using the same thresholds set in fig 12. (Left and right), figure 15. shows how the routing method makes decisions. Firstly, it analyses the routing table for the environmental sensor values of each node, anything above the thresholds is removed as potential candidates.

Table 4. The fuzzy ruleset utilised in this scenario.

Rules	Input	Output
1	If ExCo is Clear and Bkcnt is Dark and Certainty is Certain	Wireless
2	If ExCo is Turbid	Wired
3	If Bkcnt is Bright	Wired
4	If Certainty is Uncertain	Wired

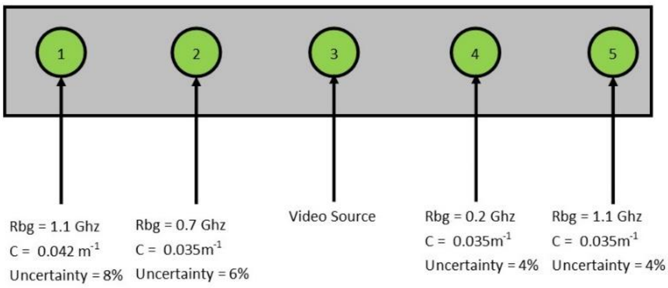

Fig 15. An abstract illustration of five nodes mounted along the pipeline, along with the parameters used for routing, before the routing has commenced.

As can be seen, 1 and 5 both have background noises above 1Ghz, so these are eliminated as candidates as seen in fig 16.

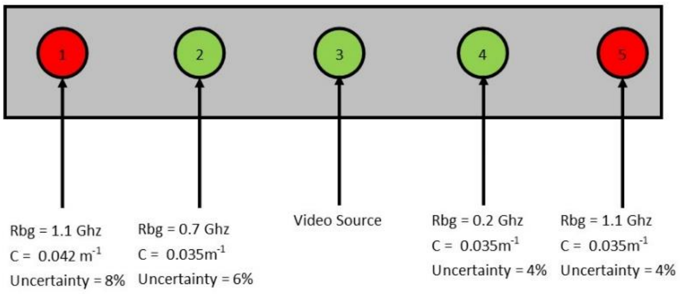

Fig 16. The same nodes once the first stage of the process has been carried out, eliminating nodes that do not meet requirements for successful transmission.

Following this process, the fitness evaluation was considered and selected the node with the lowest scores of ambient count rate, relay node uncertainty and extinction coefficient for transmission and a similar path to the original case is utilised, only this time it has shifted to an alternative node. Once the fitness metric is applied it is found that node 4 is the fittest for transmission, resulting in fig 17.

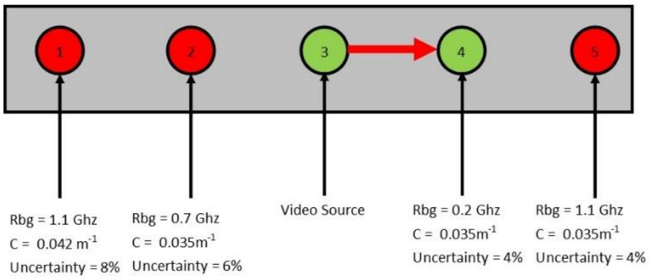

Fig 17. The same nodes once the second stage of the process has been carried out, selecting the most fit node out of those that remain to transmit the packet.

Knowing this, the power consumption and end-to-end delay calculations can be carried out as in table 5.

Table 5. The results of the network modelling in the case where an extended route via an alternative source node is taken due to obstruction.

Parameter	Value
End-to-End Delay	3.808ms
Power Consumed	24mJ

As can be seen, only a marginal increase in propagation time occurs from using these links and the significant proportion of that is from the implied processing delay in each node, given that it is assumed that energy consumption during transmission through the optical fibre links is negligible as the power demands are significantly smaller than wireless VLC, the excess energy consumption through utilisation of this fibre link would be a minimal increase. The benefit of this optional link as can be seen, as if the LOS is blocked, the novel fuzzy logic and routing mechanism can effectively route around it without the need for an acoustic link which cannot carry video over distance and consumes excessive energy. Using the modelling, it has been shown that this method, in ideal conditions, can achieve 5 Mb/sec wireless links with an SDR of 100%, therefore, it is a robust link capable of transmitting video. If there are enough of these alternative nodes and routes along the asset, then the chances of the video failing to be transmissible diminish with minimal latency and energy consumption increases. However, one element that requires future work is that video surveillance and image classifiers require a elevated processing which, in turn, consumes energy that would be a drain on battery life. Research of methods to remotely recharge this network and otherwise render it more efficient in consumption is necessary.

V. Conclusions

In conclusion, this paper presents modelling of a network, including its topology, fuzzy logic decision making process and routing technique that can robustly and energy efficiently transmit packets of 500 bytes through a 5Mb/sec wireless VLC channel in the 532nm and adapt to the unpredictable conditions of the coastal sea environment by using data from the DESERT simulator's field data, through making use of a wired connection on the seafloor and a short wired connection as the sea-surface to bypass the effect of solar noise and organic matter. It was found that with the right network topology and technologies packets can be reliably routed from source to sink without the use of an acoustic link as an alternate communication methodology. The ability of this network to robustly transmit packets will scale with the geographical network size on the seafloor as a large, diverse range of locations will offer more routes for the packets to reach the surface and avoid localised conditions driven by the environment.

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