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Design Considerations and Comparative Analysis of Cross Layer Approaches for Terrestrial & Underwater Wireless Sensor Networks

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Abstract

Due to the ever increasing demand of the deployment of terrestrial and underwater wireless sensor networks in Internet of Things applications to sense and monitor physical and environmental conditions, it becomes highly essential to design an efficient cross layer framework for Terrestrial and Underwater Wireless Sensor Networks to conserve energy & achieve low delay by considering the design issues involved and challenges encountered in these environments. This paper provides a detailed study on the design considerations and comparative analysis of Cross Layer approaches for Terrestrial & Underwater Wireless sensor networks. The cross-layer design supports in leveraging the performance of wireless sensor networks, and conservation of resources like storage, battery and bandwidth etc. Most of the cross layer architecture designs focus either on limited layers such as MAC and Routing, ignoring the functionalities of other layers or integrate all layer parameters as a single module resulting in increased complexity. This paper proposes a novel Hybrid Cross Layer Model (HCLM) which combines layer interaction through integration and Interface to achieve a good performance across the system. The main aim of the proposed hybrid cross layering model is to achieve a blended efficiency of the layers - Physical, MAC, Routing and Application. This approach, performs the cross layering in two parts - considering one at the middle layers (MAC and Routing) and other at the extreme edge layers (PHY and Application). The proposed model assures the leverage in performance along with the complexity of balancing and maintenance of good data rate resulting in energy conservation.

Keywords : Cross Layer design, Terrestrial Wireless Sensor Networks, Underwater Wireless Sensor Networks, Medium Access Control (MAC), Hybrid Cross Layer Model,

1. INTRODUCTION

Due to the ever-growing sensing & monitoring demands of Internet of Things (IoTs) applications, an explosive increase in deployment of self-configured and infrastructure-less, wireless networks has become essential to monitor physical and environmental conditions, such as temperature, sound, pressure and motion etc. and to co-operatively communicate the data through the numerous sensor nodes to a destination called sink, from where the data handed can be collected to the internet server for further processing & utilization by the users[1] Due to the explosion in IoT applications in recent years, the WSNs have been deployed extensively for essential applications such as Smart buildings(e.g., indoor climate control, home automation), health care (health monitoring, medical diagnostics), Security & surveillance, Entertainment, Urban terrain tracking and Civil structure monitoring, Environmental monitoring, Precision agriculture and animal tracking, Industrial applications, Transportation and Logistics, Smart grids and energy control systems, etc. Depending on the environment where the sensors are deployed in, and depending on the functional characteristics of the sensors, the WSNs are categorized into the primitive and complex classes with primitive class comprising the terrestrial, underwater, underground WSNs and Complex class comprising Multimedia & Mobile WSNs as shown in figure 1. Deployment of large number of wireless sensor nodes ranging from hundreds to thousands in an unstructured or structured mode capable of communicating to the sink is generally found in Terrestrial WSNs. Within the target area sensor nodes are randomly distributed normally dropped from a fixed plane in unstructured mode of deployment. Optimal placement, grid placement, and 2D, 3D placement models are used in the structured mode or pre-planned mode of deployment. As it is evident that these networks have limited battery power and in some cases fitted with solar cells as a secondary source of power. Efficient techniques like low duty cycle operations, optimal routing and delay minimizations are generally used to achieve energy conservation in these WSNs. As there is more than 70% of the earth occupied with water, exploring underwater has been a major area of research recognizing the need for deploying under water WSNs (UWSNs) and for tackling the challenges posed by the environment. A large number of sensor nodes and autonomous underwater vehicles are deployed in UWSNs where the data from the sensor nodes are collected using autonomous underwater vehicles. Long propagation delay, bandwidth and failure of sensor nodes are the major challenges in underwater communication. As it is evident that UWSNs have limited battery which cannot be recharged or replaced. Hence development of efficient underwater communication and networking techniques are the major approaches required to tackle the issue of energy conservation in UWSNs. When equipment cost, deployment, maintenance and careful planning are considered, it is found that UWSNs are more expensive than the terrestrial WSNs. In underground WSNs several sensor nodes are deployed inside the ground to monitor underground conditions to relay information from the sensor nodes to the base station and additional sink nodes that are located above the ground. Due to the high level of attenuation and signal loss in underground environment, wireless communication becomes a major challenge in addition to the limited powered battery which is difficult to recharge as sensor nodes are buried in the ground. To enable tracking and monitoring of events in the form of multimedia, such as imaging, video, and audio, Multimedia WSNs comprising low-cost sensor nodes fitted with microphones and cameras are deployed to achieve the tasks of data compression, data retrieval, and correlation over wireless communication. The major challenges faced in multimedia WSNs are high bandwidth requirements for proper content delivery, high energy consumption for data processing, and compressing techniques. It is to be noted that Multimedia WSNs have normally dynamic environments more versatile than static WSNs where a collection of sensor move on their own to sense, compute and interact with physical environment thereby providing better energy efficiency, better and improved coverage and superior channel capacity.

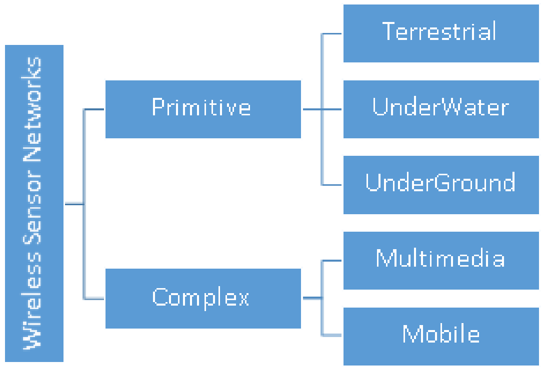

Fig1. Classification of WSNs

Cross-layer design is to share the information among the layers either through a set of key parameters or through the help of additional interfaces across the non-adjacent layers. Cross layer can be defined as an increased interaction between layers which may result in the violation of traditional flow of communication. The basic idea is not just to unnecessarily disturb the traditional architecture where enormous delay is incurred due to the communication to traverse from the first layer until it reaches last or vice versa, but to improve the interaction between the layers and reduce the delay involved in communication where layers can communicate directly to provide hints to each other regarding the data to be sent or received. Due to the enormous growing demand for the data gathering, most applications require a continuous monitoring where the node's energy and network lifetime may exhaust very soon with the traditional layered architecture. This happens because of moderate transfer rates. In wireless sensor networks it is required to exploit the given duty cycle efficiently. For Conventional communication models like OSI and TCI/IP, it is a huge challenge to utilize the duty cycle efficiently and to conserve energy. Conventional reference models for communication, standardized the layers in such a way to allow their development independently in future. In other words, these models prevent the modifications of one layer affecting the other layer. The built-in mechanism of conventional models is that the higher layers accept primitive services from the lower layers. As wireless sensor networks are different from the other set of networks, they need increased coordination and interaction between the layers. Cross layer design tries to address these necessities and continue to maintain the functionalities associated with the original layers. Cross layer gears up the data transfer rate and gives a great support in efficient use of network resources. Considering the need for reducing enormous delay in communication and achieving reduced energy consumption, several approaches and techniques have been proposed in the literature to show the importance of cross-layer design. XLP approach introduced in [42] and other cross layer techniques discussed in [45], [48] and [49] involve cross layering ranging from 2 to 4 layers. Among these XLP uses a unified scheme that blends common protocol layer functionalities. While [45] also uses parameters from different layers of stack involving physical, MAC & Network. Scheme in [48] integrates all the 4 layers. Though MC-LEACH in [49] is a cross-layer routing protocol, it interacts with physical, MAC and network layers. The other set of cross layer schemes focus on cooperation of MAC and routing layers [43]. It is observed in few schemes like CL-MAC [44] and [46] either one of MAC or routing enhance themselves taking the help of the other. An observation of cross layering schemes used in underwater WSNs also converge us towards a similar conclusion that most of the works like [52], [53] focus on enhancement of routing layers by exploiting the information from either MAC or Physical layers.

The main objective of this work is to focus on the design of cross layer framework for Terrestrial and Underwater Wireless Sensor Networks by considering the design issues involved and challenges encountered by performing comparative analysis of the algorithms and approaches proposed in the literature. The paper also proposes a novel cross layer frame work with an intention to achieve high data rates, throughput, and energy efficiency, that make a variation from the existing cross layer models which are either too complex covering all layers in a single module, or focusing on just enhancement of routing layer protocol by exploiting the other layer functionalities. This frame work is designed with a concept to achieve cross layering over all layers and still retaining the complexity balance of the system. The cross layering is done in two parts: (i) integration part and (ii) interfacing part. Though, Terrestrial and Underwater WSNs have a difference in their characteristics, the requirement of any WSN is to gather the data from the environment they are deployed in and to successfully forward to the destination nodes (usually sink nodes). Various cross layer works have been carried out both in Terrestrial and Underwater but the proposed frame work is built in a way such that, it works for both Terrestrial and Underwater. Hence, this frame work can be called as an Amphibian cross layer too. The observation and analysis of the various existing cross layer models, conclude that, most of the optimization focus is on routing functionality, and lacking the projection on optimization of other layers. In few cases, it is tried to bring all the layer functionalities into a single compact module. Though compaction is a good idea, choosing a limited set of functional parameters affect the overall performance. While HCLM, is designed with a concept to bring the middle layers (MAC and Routing) still nearer to each other through integration to present a collaborative efficiency and simultaneously building a bridge of interface between the extreme edge layers (Physical and Application) to hint each other and support in achieving a better data rate. As the transport layer has minimal functionality, it is left to function as usual.

The rest of the paper is organized as follows. An overview on the functionalities of the PHY, MAC, Routing, Transport and Application Layers is presented in Section 2. A detailed comparative analysis of MAC and Cross-layer approaches of WSNs is presented in section 3 considering both the terrestrial & Under-water WSNs. Section 4 discusses the proposed Hybrid Cross Layering Model (HCLM) highlighting the integration of MAC layer into routing layer, interfacing between Application and PHY layers and further providing complexity computation and system analysis which is then followed by Conclusion & future work in the next section.

2. OVERVIEW OF LAYER FUNCTIONALITIES IN WSN

In this section, we briefly present the functionalities of the following layers - PHY, MAC, Routing, Transport and Application Layers.

PHY layer functionalities – The PHY layer functionalities cover the tasks performed by the transceivers of sensor nodes to transmit & receive data using carrier frequency selection and generation, encryption and decryption, modulation and demodulation [56]. The amount of data transmitted or received also termed as the data rate is an important factor to be considered, in addition to the baud rate as power consumption increases with baud rate increase. Normally sensor nodes are put to sleep during their inactive period more frequently to save and conserve large amount of energy being wasted in idle periods and using higher date data rate to transmit and receive large amount of data in small active periods.

MAC Layer Functionalities - The MAC layer [2] is the one that plays the most important role in terms of real-time guarantees, energy efficiency, scalability, and QoS issues. WakeupRadio based MAC protocols can be divided into protocols that address (only the MAC layer) and in protocols that rely on interactions between different layers (cross layer) [3]. The design challenge is not only to provide novel solutions that target a specific attribute, but also to deal with trade-offs between all attributes. Thus, an effective MAC protocol for WSNs must consider these attributes. However, the weight of each attribute may vary from one application to another due to the wide variety of WSN applications and their diverse requirements. For instance, an application might be more sensitive to real-time guarantees. While, others may be more demanding in terms of network lifetime and thus energy consumption. For that reason, there is no predominant standard solution for WSNs, but rather a large set of MAC protocol proposals, while each approach is more suitable for a certain application.

Routing Layer Functionalities - To minimize energy consumption, routing techniques proposed for WSNs employ some well-known routing tactics as well as tactics special to WSNs, e.g., data aggregation and in-network processing, clustering, different node role assignment, and data-centric methods [4]. The major challenges to be taken into account when designing routing protocols for WSN are difficulty experienced in allocating universal identifiers scheme for large number of sensor nodes resulting in inefficient use of classical IP-based protocols, requirement of compulsory flow of detected data from large number sensor source nodes to the base station, where in these detected data have significant redundancy in most of the cases. In such cases efficient mechanisms are required to exploit such redundancies by the routing protocols to achieve more efficient utilization of the available bandwidth and energy. It is also important to restrict firmly the wireless sensor motes when considering transmission energy, bandwidth, storage and on-board energy [5][6].

Transport Layer Functionalities -The necessity of transport layer protocol in WSNs has been debated[58]. Suggestions found regarding the transport layer functionalities include (i) loss detection and recovery can be handled below the transport layer and mitigated using data aggregation, and (ii) congestion is not an issue because sensor nodes spend most of the time sleeping resulting in sparse traffic in the network. To prolong the lifetime of a WSN, an ideal transport layer needs to support reliable message delivery and provide congestion control in the most energy efficient manner possible.

Application Layer functionalities - The application layer is liable for traffic management, security management and offers software for numerous applications that convert the data in a clear form to find positive information. Wireless Sensor Networks arranged in numerous applications in different fields such as agricultural, military, environmental, medical, home, & other commercial areas.

3. COMPARATIVE ANALYSIS OF MAC & CROSS LAYER APPROACHES

3.1 MAC PROTOCOLS FOR TERRESTRIAL WSNs

In this section, we present a detailed comparative analysis of Foundation MAC protocols and Advanced MAC protocols for Terrestrial WSNs.

3.1.1 Foundation MAC protocols for Terrestrial WSNs

Foundation MAC protocols for Terrestrial based on which a numerous varied version have arrived, each contributing towards the betterment of the performance in terms of energy efficiency and end-to-end delay reduction. The very foundation MAC IEEE-802.11[7] does the basic channel allocation by sensing the carrier and transmitting data and using back-off algorithm to overcome collisions with no mechanism to conserve energy, PAMAS[8] proposes power off nodes to avoid idle listening and avoid over hearing. It also makes use of in-channel signalling. S-MAC[9][10], a benchmark MAC has two variations - first one is a simple one with duty cycle while the second version makes use of adaptive listening. T-

MAC[11] is an advancement of S-MAC and makes use of Future Request To Send(FRTS). B-MAC[12] uses a very flexible interface and it depends on clear channel Assesment(CCA). Wise-MAC[13] makes use of synchronized preamble sampling. This falls under the basic category of Low PowerListening(LPL) protocols. X-MAC[15] also falls under the same category of LPL. D-MAC[14] a different approach of duty cycle, where the nodes participate in staggered duty cycles. Z-MAC[16] is a hybrid protocol that utilizes both TDMA & CDMA techniques. P-MAC [17] protocol is designed in such a way that it determines its wake-up schedule based on the upcoming traffic. In R-MAC[18] Reservation based MAC, a setup control frame is used to travel across multiple hops and accordingly the upcoming data packet delivery along the route is scheduled.. A-MAC[19] is designed to solve the end-to-end delay problem by using the surplus energy after pre-configured network lifetime. Thus, each MAC lays a foundation for every basic technique in medium access control. A detailed comparative analysis of Foundation MAC protocols for Terrestrial WSNs is presented in table 1 considering the following evaluation parameters – Techniques introduced, Design Primary & Secondary goals, Category to which they belong(CSMA, TDMA, Hybrid), Strengths & Weaknesses, Attempts to reduce idle listening, Signalling, Hidden terminal problem handled, Power conservation at every node, Average power conservation, Synchronization, Effect of transmission overhead, and Additional achievements

3.1.2 Advanced MAC Protocols for Terrestrial WSNs

In this section, we present comparative analysis of recent advanced MAC protocols proposed in the literature for terrestrial WSNs. A huge set of preamble sampling protocols are discussed in [20] that use preamble sampling techniques which provide extremely low energy consumption at low loads and have a simple operation. This technique eliminates the need for synchronisation requirements. A limitation of this approach is it works well for low loads but, as the load increases its performance degrades. A new network-wide optimized time division multiple access (TDMA) scheduling scheme for wireless sensor networks (WSNs) is proposed in [21]. It formulates the rate allocation problem based on the Lexicographic Max-Min (LMM) criterion, which takes fairness, throughput maximization, and slot reuse into consideration. It requires an iterative calculation of proper slot reuse control parameter. D-TDMAC [22], based on TDMA MAC, designed for dynamic sensing applications. Cluster Heads (CH) allocate slots to the nodes while free slots can be efficiently utilized by remaining nodes. Interference due to intra cluster or inter cluster communication is avoided by D-TDMAC. Overhearing is also significantly eliminated. But it faces overhead during allocation of slots.as slot requests may create a bottle neck problem at CH. A Bitmap-assisted Shortest-job-first based MAC for hierarchical wireless sensor networks presented in BS-MAC [23] transmits more data with less delay and less energy consumption. Its contributions are (i) using small size time slots. (ii) having more number of time slots than the number of member nodes. (iii) Shortest job first (SJF) algorithm to schedule time slots. (iv) Short node address (1 byte) to identify the member nodes. SJF's drawback of starving the non-Shortest Job may hinder the nodes that require more number of data slots. BEST-MAC [24] bitmap-assisted efficient and scalable TDMA-based MAC (BEST-MAC), is proposed for adaptive traffic in hierarchical WSNs that can be deployed in the smart cities. Compared to BS-MAC which uses SJF, BEST-MAC uses Knapsack algorithm for scheduling time slots. Bottleneck problem may arise at cluster heads. The work in [25] proposed a new duty cycle management scheme for the MAC protocol to reduce the energy consumption by the sensor nodes there by improving the network lifetime. According to this, the total duty cycle is divided into two equal parts, one part is used for transmission of own data and another part is used for transmission/reception of neighbor node's data. If there is no data available for either own or neighbor nodes then it will go into the sleep mode thus saving the energy consumption. Limitation is that, there is a more probability of latency for neighbor nodes data transmission because the part of duty cycle may be inadequate if there are more neighbors ready to transmit. A three-dimensional group management MAC (3-D GM-MAC) is a MAC protocol designed for 3-dimensional wireless mobile sensor networks. The work in [26] proposed an updated version of 3-D GM-MAC with some fixed sensor nodes. It is proposed to improve the stability of WSN by sending and receiving guaranteed information to/from sensor nodes. It reduces again and again resetting a group number and thus achieves an increased life time of the network. A limitation issue is that, the uniformity of a sensor node life is reduced. The approach discussed in [27] believes that not only is it possible for sensors to move around, but sinks can also move around i.e. it assumes WSNs as a mixture of mobile and stationary nodes. In this work, Anchor-based Group Relay-MAC (AGR-MAC) is proposed for the WSN with mixed sensors. Life time of the network is shortened when the number of sensor nodes is increased. A new technique for MAC with a multilayer approach added adaptive listening is presented in [28]. This leverages a better energy efficiency and throughput. But collisions may increase as the number of nodes increase. A new event driven medium access control (MAC) protocol, which is called modified routing-enhanced duty-cycle MAC (MRMAC) proposed in [29]. MRMAC protocol improves data transmission delay while reducing the energy consumption in multi-hop WSNs. At the beginning of a time cycle, the source node transmits the pioneer control frame called PION to ensure the synchronization of all the intermediate nodes throughout the data transmission path. It is observed that it achieves low latency for a smaller number of hops and but latency increases as the number of hops increases. In [30] PAX-MAC Preamble Ahead Cross-layer Medium Access Control preambles propagate ahead of data packet, prospecting the route towards sink node, while the message is sent some hops later. This protocol takes the data packet size into account in order to maintain an optimal distance between preamble and data to minimize latency. Maintenance of optimal distance between preamble and data is crucial in this approach to achieve minimum latency. A detailed comparative analysis of Advanced MAC protocols for Terrestrial WSNs is presented in table 2 considering the following evaluation parameters – Mechanisms used, , Design Primary & Secondary goals, Strengths & Limitations.

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Table 1: Comparative Analysis of Foundation MAC protocols for Terrestrial WSNs

Channel access protocol / Issue	MAC IEEE-802.11 (1997) Ref[7]	PAMAS (1998) Ref[8]	Simple S-MAC (2002) Ref[9]	S-MAC with Adaptive sleep (2004) Ref[10]	T-MAC (2003) Ref [11]	B-MAC (2004) Ref [12]	Wise-MAC (2004) Ref [13]	D-MAC (2007) Ref [14]	X-MAC (2006) Ref [15]	Z-MAC (2005) Ref [16]	P-MAC (2005) Ref [17]	R-MAC (2007) Ref [18]	A-MAC (2007) Ref [19]
Techniques introduced	Sensing the carrier and transmitting data	Powering off nodes to avoid idle listening and over hearing, and usage of In- channel signaling	Duty cycles introduced and formation of virtual clusters for auto-synchronization to avoid control overhead	Traffic adaptive wake-up introduced to reduce the delay	Introduced adaptive duty cycles which dynamically end active part in order to reduce the idle listening, and introduced FRTS and full-buffer priority to reduce latency	Introduces a very flexible interface	Synchronized preamble sampling	Staggered duty cycle	Uses a shortened preamble sampling with targetID	Exploits the benefit of CSMA &TDMA	The sleep-wakeup schedules are determined adaptively based on nodes own traffic and that of its neighbors	A setup control frame is introduced to travel across multiple hops and schedule the upcoming data packet delivery along that route	Utilization of the surplus energy remaining after pre-configured network lifetime to reduce end-to-end latency
Primary goal	Throughput maximization & transmission delay minimization	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency
Secondary goal	-	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization	Throughput maximization & transmission delay minimization
Category	CSMA-based	CSMA-based	CSMA-based	CSMA- based	CSMA- based	CSMA- based	CSMA- based	CSMA-based	Hybrid	TDMA & CSMA based	Hybrid	Hybrid	hybrid
Strength	Traditional and standardized	Reduction of idle listening and over hearing	Synchronized sleep period,	Adaptive sleep	FRTS, full buffer priority	Flexible interface, ultra low power operation	Synchronized preamble sampling	Staggered active/ sleep schedule	Shorten preamble to retain low power listening		Traffic-based sleep-wake-up schedules		Focuses on avoiding network partitioning due to occurrence of sensing holes

Weakness	Unsuitability to WSNs	Separate channel used for signaling	Sleep latency, synchronization overhead	Synchronization overhead		Avg latency is slightly high	Duty cycles increase as the number of senders increase. Receiver has to wait for a long period until the preamble is completed		Duty cycles increase linearly with number of senders				
Attempts to reduce idle listening	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	yes
Signalling	In-channel	Uses Separate channel	In-channel	In-channel	In-channel	Uses preamble	Uses preamble	In-channel	In-channel	In-channel	In-channel	In-channel	In-channel
Hidden terminal problem handled	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW	Uses MACAW
Power conservation at every node	None	High	High	high	Medium	Very high	Medium	medium	medium	medium	medium	medium	medium
Average power conservation	None	High	High	High	medium	Very high	Medium	medium	medium	medium	medium	medium	medium
Synchronized	No	No	yes	Yes	No	Yes	Yes	Yes	yes	yes	yes	yes	yes
Effect of transmission over head	Very high	High	low	Low	low	low	medium	Medium	low	Low	Low	Low	low
Additional achievements	-	-	Addresses control over head to an extent by using message passing	Reducing sleep latency using adaptive wakeup	Addresses early sleeping problem using FRTS and full-buffer priority	-	Low power listening	Addresses collision using MTS	Low power listening along with reduced delay and avoidance of overhearing	-	-	-	-

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Table 2 : Comparative Analysis of Advanced MAC protocols for Terrestrial WSNs

Observations	**Ref [21]**	**Ref [22]**	**Ref [23]**	**Ref [24]**	**Ref [25]**	**Ref [26]**	**Ref [27]**	**Ref [28]**	**Ref [29]**	**Ref [30]**
Mechanism	Optimized TDMA, LMM criterion	Based on TDMA MAC D-TDMA	Bitmap assisted shortest job first	Bitmap assisted efficient and scalable TDMA	A new duty cycle management scheme	An updated version of 3-D GM-MAC	Anchor based group relay mechanism	A multi-layer approach	Division of duty cycle	Propagation of preamble ached of data packet
Primary Goal	Simultaneous achievement of MAX throughput & fair rate allocation	To reduce energy consumption	To efficiently handle adaptive traffic loads of all members	To improve quality control of data traffic	To reduce energy consumption by nodes and improve network life time	To improve the stability of WSN	To address the needs of mixed sensors	To achieve improvement in throughput	Lower delay and lower energy consumption	To minimize latency
Secondary	Achieving good trade off between fairness & throughput	To reduce overhearing	Minimization of control over head & energy consumption	Minimization of control over head and energy consumption	Reducing latency	To increased network life time	---	Collision avoidance	---	Energy efficiency
Strength	TDMA schedule	Organisation into clusters & dynamic allocation of free slot	i)Large no of small time slots ii)SJF algorithm iii)Short node address	i)Large no of small time slots ii)knap sack algorithm iii)Short node address	Division of duty cycle into 2 parts	Guaranteed information exchange between sensor nodes	Anchor nodes are not power constrained	Adoptive listening	PION packet, CS period repetitive sleep periods and over hearing for ACK	Cardinalities of FCS (forwarding candidate set)
Limitation	Requires an iterative calculation of proper slot reuse control parameter	Allocation of free slot to the nodes in the same frame	Priority given to the nodes with less no of data slot request	Bottleneck problem at cluster heads may arise	Latency may increase if there are more no of neighbour nodes ready to transmit	Uniformity of a sensor node life is reduced	Life time of network is shortened when the no of sensor nodes increased.	Choosing no of layers is crucial. In non-coherent as no of layers increase delay increases	Increase in no of nodes may effect the performance	Maintenance of optimal distance between preamble and data is crucial

3.2 MAC PROTOCOLS FOR UNDERWATER WSNs

In this section, we present a comparative analysis of MAC protocols for Underwater WSNs. The approaches proposed in [31], Aloha-CA (Aloha- Collision Avoidance) and Aloha-An (Aloha-Advanced Notification) are capable of using the long propagation delays to their advantage. Both schemes can boost the throughput by reducing the number of collisions. Particularly, the Aloha-AN, technique significantly reduces the number of unproductive transmissions, but it requires additional cost to achieve a better throughput and collision avoidance. Slotted FAMA [32] uses Time slotting to eliminate the need for excessively long control packets, thus providing savings in energy. Fairness in high traffic situations, high propagation delay in long slot situation, and adaptive power control are the few issues faced. T-Lohi [33] employs a tone-based contention resolution mechanism that exploits space-time uncertainty and high latency to detect collisions and count contenders, achieving good throughput across all offered loads. T-Lohi is found to be stable and fair under both low and very high offered loads. T-Lohi required additions to work in multi-hop networks. MACA-U [34] is the original MACA adapted for use in underwater networks. Due to its simplicity and throughput stability it can be adopted as a reference MAC protocol for underwater networks. There are chances for unfairness in the backoff algorithm. UWMAC [35] proposes a CDMA-based power controlled medium access protocol in order to utilize inside a formed cluster both the transmitter and receiver based CDMA and to make the cluster heads communicate with the base station using a TDMA based schedule. It uses CDMA as it provides resilience to multi-path and Doppler's effects prevalent in underwater environments, but it results in overhead of table maintenance every time a CTS received and also the Overhead of NAV maintenance. A slotted based Underwater Power Control MAC protocol (UPC-MAC) [36] leverages transmission power and long propagation delays to enhance the spatial reuse efficiency. UPC-MAC is a reservation based channel access scheme and makes use of long propagation delays to collect neighbouring nodes' sending requests and channel information between these senders and receivers. The performance of this MAC varies with the variations in topology. The MAC design in [37] explicitly accounts for characteristics of UWSNs such as long propagation delays and typically high bit error rates. MACA-APT also embeds a cross-layer S&W ARQ scheme causing a minimal increase in the protocol overhead. Slotted-FAMA based MAC protocol for underwater wireless sensor networks with data train (SFAMA-DT) [38], improves the channel utilization by forming a train of data packets of multiple transmission pairs during each round of simultaneous handshakes, which overcomes the multiple RTS attempts problem of Slotted-FAMA in high traffic environments and greatly reduces the relative proportion of time wasted due to the propagation delays of control packets. It still requires an efficient mechanism to solve the hidden terminal problem and RTS/CTS collision problem. In UCMAC [39], a source identifies co-operators and provides its destination with a list of the co-operators while also delineating their proximity to the destination. For erroneous reception of data packets, the destination then requests retransmission to the co-operators in a closest-one-first manner. This deals with betterment of system throughput, latency, single-hop packet delivery ratio (PDR), and energy efficiency. This MAC protocol may include the overhead of cooperation, such as the maintenance of co-operators. A MAC protocol (BSPMDP-MAC) [40] for an underwater acoustic sensor network is based on the belief state space. This protocol can averagely divide the time axis of a sensor's receiving nodes into n slots. The action state information of a sensor's transmission node was divided by the grades of link quality and the residual energy of each node. This protocol put efforts to reduce the collision rate of data packets, improve the network throughput and transmission success rate of data packets, and reduce the energy overhead of the network. This protocol recommends transmission nodes with better link quality as nodes for data packet transmission first and then, nodes with higher residual energy used as data forwarding nodes. In this case better link quality nodes are exhausted first. A load-based time slot allocation (LBTSA) protocol [41] selects the slot allocation scheme, from a set of possible schemes, according to the instantaneous network load. Then, based on the relative priority of the nodes and the optimal number of backoff stages, the host node selects the optimal access control protocol. Its achievements are adaptability to changing network loads, lower end-to-end delay and maximization of throughput. This takes advantage of TDMA and CSMA/CA and time slot allocation is a crucial factor affecting system performance. A detailed comparative analysis of MAC protocols for Underwater WSNs is presented in table 3 considering the following evaluation parameters – Mechanisms used, , Design Primary & Secondary goals, Strengths & Limitations.

3.3 CROSS LAYER DESIGN FOR TERRESTRIAL WSNs

In this section, we discuss the work carried out in the area of cross layer design for terrestrial WSNs so far. The approach XLP [42], presents an unified scheme that blends common protocol layer functionalities into a cross-layer module considered as a way to efficiency. The cross layer protocol (XLP) proposed in this paper achieves congestion control, routing, and medium access control in a cross-layer fashion. In order to realize efficient and reliable communication in WSNs, the XLP uses a design principle based on the cross-layer concept of initiative determination achieving receiver-based contention, initiative-based forwarding, local congestion control, and distributed duty cycle operation A disadvantage could be, every time the communication has to start, the nodes have to cross-check all the thresholds related to different layers as a single module and as well as they need to perform their functionalities as usual. This may result in decreased data transfer rate. The work in [43] proposed a high reliability and energy-efficient cross-layer protocol (HREE) to solve tailings reservoir on-line monitoring WSN's problems of interferences and energy-limitations. By the cooperation of reliable efficient uneven clustering routing protocol (REUC) and single interface based multi-channel MAC protocol **(**SIMC), HREE tries to gain good lifetime and reliability improvement in tailings reservoir on-line monitoring WSN. On the other hand, HREE has a very complex structure and its focus is only on MAC and Routing. CL-MAC [44] presents the capability of handling

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Table 3: Comparative Analysis of MAC protocols for Underwater WSNs

Observations	**Ref [31]**	**Ref [32]**	**Ref [33]**	**Ref [34]**	**Ref [35]**	**Ref [36]**	**Ref [37]**	**Ref [38]**	**Ref [39]**	**Ref [40]**	**Ref [41]**
Mechanism	Exploiting long propagation delays	FAMA based	Exploits space time uncertainty	Important in state transition rules, packet forwarding	Transmitter based and received based CDMA inside cluster and TDMA to communicate with BS	Reservation based channel accesses scheme	i)transmits of a train of packet of adoptive size ii)Embeds a cross layer S&WARQ scheme	Forming a train of data packets	Cooperative communication	Better link quality nodes use recommended for transmission first then high residual energy nodes	Load based time slot allocation
Primary Goal	Boosting throughput	Energy saving	Good throughput across all offered loads	Adaptation of terrestrial MACA for multi hop underwater networks	Latency and throughput improvement	To improve system performance	To handle long propagation delay and high bit error rates	To improve channel utilisation	Improve throughput latency	Network throughput, transmission success rate of data packets	To lower end to end delay and maximising of throughput
Secondary	Reducing no of unproductive transmission	To eliminate need of long control packet	--	--	Overall network life time	--	To demonstrate impact of packet train size on performance of APT	To over come the multiple RTS attempts problem of S-FAMA	Single hop PDR, energy effeminacy	To reduce energy over head of network	--
Strength	Aloha CA simple and scalable Aloha -AN scalability	Uses time slotting	Stable and fair under both low and very high offered loads	Simplicity and throughput stability	Resilience to multipath and Doppler's effect	Nash equilibrium to transmission power adjustment	CRA including delivery report to notify the sender about correctly received packets	greatly reduces the relative proportion of time wasted due to the propagation delays of control packets	Mechanism to resolves erroneous reception of data packets,	reduced collision rate of data packets, improve the network	Adaptability to changing network nodes
Limitation	i)Aloha -CA has dependence on PT ratio. ii)Lag time degrades throughput in Aloha-AN	Issues of fairness high propagation delay and adaptive power control	Require additional suppose to work in multi-algorithm hop networks	Chances of unfairness in the back off algorithm	Over head of table maintenance every time CTS received and over head of NAV maintenance	Effected by topology changes	Performance is better only for low and intermediate packet generation rates	An efficient mechanism is still require to solve hidden terminal problem and RTS/CTS collision	Overhead may stem from cooperation	Better link quality nodes are exhausted first	Time slot allocation is a crucial factor

varied traffic loads efficiently. CL-MAC has all the information available via the routing layer. This allows it to have a better assessment of the current traffic load i.e. it can make a more informed decision when setting up a flow. It is found to have an improvement in substantial reduction of end-to-end latency, but with a penalty of energy sacrifice. In [45] parameters from different stack layers (i.e., physical, MAC, and network) are presented to a fuzzy logic system controller which makes a next hop routing decision. The parameters used in [45] are not optimized. In [46], based on synchronization scheme and adaptive listening scheme, a cross-layer route scheme is designed that utilizes the synchronization information and queue message to establish and update route. The extended listening and adaptive regular listening scheme is used in this to dynamically adjust listening schedule, which effectively reduces sleep delay and prevents node from buffer overflow. But, dynamic adjustment of listening schedule occurs too frequently that may drain off more energy. The integrated cross-layer framework proposed in [47] termed as SchedEx-GA takes into account both MAC layer and network layer. It has a limitation, i.e. it models all traffic as periodic traffic. The algorithm used in the work ensures that traffic of high periodicity is assigned many opportunities for potential transmissions. The proposed model in [48] integrates four layers in the network operation: application (node location), network (routing), medium access control (MAC) and physical layers. It requires to minimize more control packets especially RREQ packets as they are also broadcast packets. MC-LEACH proposed in [49] a cross-layer routing protocol that deals with physical, MAC, and network layers for the analysis of energy consumption at individual node as well as in whole network. An overhead of this approach is, each node has to maintain the routing table and as well as routing tree. In [50] a cross layer technique is designed to address the energy efficiency issues, and used to optimize the energy from one-layer parameter by others. For end-to-end delay this considers virtual end-to-end packet rate selection and congestion control feedback mechanism. Thus, reduces the packet loss with the support of data-rate adaptation technique. A limitation could be a single optimization module for all layers. A detailed comparative analysis of cross-layer approaches for Terrestrial WSNs is presented in table 4 considering the following evaluation parameters – Mechanisms used, Layers involved, achievements & limitations.

3.4 CROSS LAYER DESIGN FOR UNDERWATER WSNs

In this section, we discuss the work & investigation carried out in the area of cross layer design for Underwater WSNs so far. The work in [51] proposed a coherent cross-layer framework to optimize communications in UW-ASNs focusing on end-to-end improved network performance in terms of both energy and throughput when highly specialized communication functionalities are integrated in a cross-layer module. It has a requirement of scheduling mechanisms to simultaneously handle traffic classes with different QoS requirements and to provide fair congestion. A novel cross-layer routing protocol based on network coding (NCRP)[52] proposed for UWSNs utilizes network coding and cross-layer design to achieve efficient data packets forwarding to sink nodes using greedy mechanisms. It uses beacon messages only for initial routing construction and with the data packets transmissions routes are automatically updated but uses a proper coding scheme to avoid repetitive data transmissions. A location free single copy protocol RECRP proposed in [53] uses Reliable Energy-efficient Cross-layer Routing Protocol to achieve high data delivery rate by adopting the physical layer information such as Doppler scale shift measurement, Received Signal Strength Indication (RSSI) to estimate the distance without the need for extra hardware for localization. But it is observed that the transmission power of the RECRP increases as the transmission distance increases. NADIR proposed in [54] for Network Aware aDaptIve Routing is fully distributed and self-adaptive. It supports the use of multiple coded modulation schemes and the usage of cross-layer information to interact with the physical layer. Link quality information is exploited along with energy and topological data in order to select the relay node to use. A limitation is deciding on different modulation and coding schemes to be selected resulting in different link qualities, bit rates and communication ranges. The scheme in [55] minimizes the number of transmitted control packets and also reduces the re-transmission of data packets, by predicting the channel status rather than exchanging an excessive number of control packets which typically convey expired channel state information. It requires an additional mechanism to reduce unwanted re-transmissions. A detailed comparative analysis of cross-layer approaches for Underwater WSNs is presented in table 4 considering the following evaluation parameters – Mechanisms used, Layers involved, Achievements & Limitations.

Table 4: Comparative Analysis of Cross Layer approaches for Terrestrial & Underwater WSNs

Observations **X-layer Schemes**	**No. of layers involved**	**Layers involved**	**Mechanism**	**Achievements**	**Limitations**	**Type of WSN**
Ref [42]	4	Physical, MAC, Network, Transport layers	Unified scheme blends common protocol layer functionalities into a cross-layer module	achieves congestion control, routing, and medium access control in a cross-layer fashion	Thresholds have to be verified before initiation of every communication	Terrestrial
Ref [43]	2	MAC & Routing	Optimization of Route layer by exploiting the MAC layer information	To solve problems of interferences and energy-limited in WSN	very complex structure and it’s focus is only on MAC and Routing	Terrestrial

Observations **X-layer Schemes**	**No. of layers involved**	**Layers involved**	**Mechanism**	**Achievements**	**Limitations**	**Type of WSN**
Ref [44]	2	MAC & Routing	CL-MAC has all the information available via the routing layer	presents the capability of handling varied traffic loads efficiently	It is found to have an improvement in substantial reduction of end-to-end latency, but with a penalty of energy sacrifice	Terrestrial
Ref [45]	3	physical, MAC, and network	Routing layer makes next hop decision based on the other layer parameters involved in cross layer	maximizing the network lifetime	parameters of the proposed algorithm in this work are not optimized	Terrestrial
Ref [46]	2	MAC and Routing	utilizes the synchronization information and queue message to establish and update route.	adaptive regular listening scheme is used in this to dynamically adjust listening schedule, which effectively reduces sleep delay and prevents node from buffer overflow	If dynamic adjustment of listening schedule occurs too frequently it may drain off more energy	Terrestrial
Ref [47]	2	MAC layer and network layer	introduced an integrated cross-layer framework, SchedEx-GA, spanning MAC layer and network layer	traffic of high periodicity is assigned many opportunities for potential transmissions.	MAC layer and network layer	Terrestrial
Ref [48]	4	Application, Network, MAC & Physical	This model integrates four layers in the network operatio n	Minimization of energy consumption, less control packet overhead, minimization of end-to-end delays	requires to minimize more control packets especially RREQ	Terrestrial
Ref [49]	3	Physical, MAC, network layers	analysis of energy consumption at individual node as well as in whole network.	Optimization of energy consumption energy consumption	An overhead is, each node has to maintain the routing table and as well as routing tree.	Terrestrial
Ref [50]	4	Physical, MAC, Network, and Transport layer	Uses congestion control feedback mechanism. Also uses data-rate adaptation technique	Handles end-to-end delay. Reduces packet loss	Single optimization module for all layers may lead to complexity	Terrestrial
Ref [51]	3	Physical, MAC, Routing	To jointly control routing, MAC & physical functionalities	Improvement in end-to-end network performance and improvement in terms of both energy and throughput	Difficulty to simultaneously handle traffic classes with different QoS requirements and to provide fair congestion.	Under Water
Ref [52]	2	Transport and Routing layers	NCRP takes full use of multi-cast feature in underwater wireless networks and designs an efficient way to find a reliable data transmission link	Improvement of performance in terms of energy consumption, end-to-end delay and packet delivery ratio	real-time transmission rate control and route maintenance have great impact on channel utilization and Packet delivery ration	Under Water
Ref [53]	2	Routing and Physical layers	Information of the physical layer is utilised by the routing layer, with out any necessity of extra hardware for localization	Betterments in energy cost, packet loss ratio, and end-to-end delay	As the transmission distance increases, the transmission power of the RECRP also increases	Under Water

Observations X-layer Schemes	No. of layers involved	Layers involved	Mechanism	Achievements	Limitations	Type of WSN
Ref [54]	2	Routing and Physical layers	Link quality information is exploited along with energy and topological data in order to select the relay node.	Adaptive strategy gives better network performance in terms of packet delivery and energy consumption in the presence of unreliable channels	deciding on different modulation and coding schemes to be selected	Under Water
Ref [55]	2	Routing and Physical layers	Each transmitting node evaluates the quality of links to its next hop neighbor relay nodes.	energy per bit consumption savings, high packet delivery ratio and low latency.	requires an additional mechanism to reduce unwanted re-transmissions	Under Water

4. HYBRID CROSS LAYERING Model (HCLM)

In this paper we propose a novel Hybrid Cross Layering model(HCLM) which is achieved by the combination of two violations of the standard layered approach (i) Layer Interaction Through Integration (ii) Layer Interaction Through Interface. The goal of the interaction between layers is to achieve a good performance across the system. The proposed cross layering begins with an aim to result in a blended efficiency of the layers (physical, MAC, Routing and Application). In Cross Layer Designs which exploited one layer to enhance other layers may have the gaps like non-exploited layer functionalities. On the other hand, the unified single module designs, either result in an extended complexity or an inadequate interaction. HCLM as shown in figure 2, neither focus on a single layer enhancement nor uses a single unified cross layer module. In contrast to the previous works, it maintains a wide range of interactions between layers without converging at a single point. For accomplishing this, it takes support of integration - for the nearer layers and interfacing of the farer layers.

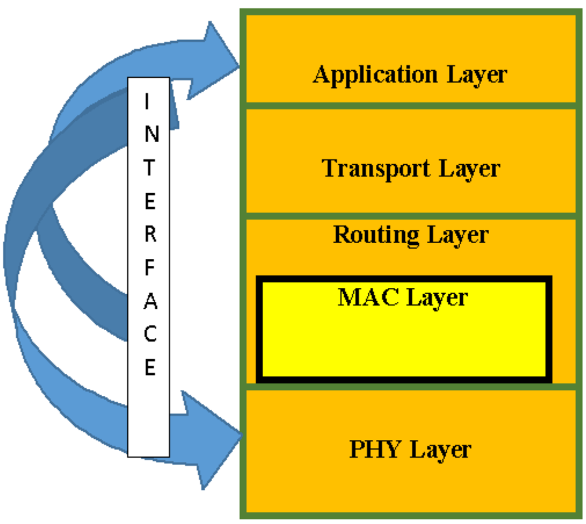

Fig 2 A model of Hybrid Cross Layering (HCLM)

4.1 Integrating MAC Layer into Routing Layer

As the MAC is integrated into the Routing layer, it is provided with the beneficiary of the easy routing. This easy routing can be achieved by utilizing the capabilities of Medium Access Control. A desired MAC can be integrated into a desired Routing layer. The key functionalities of routing layer are in-network processing and routing towards the sink. As the MAC layer functionality is to control the medium access avoiding collisions, the same information can be used to route hop by hop. Thus, it is eliminating the necessity of overhead involved in the maintenance of complex routing tables. This makes the Routing protocol module in Hybrid Cross Layer Model a light-weight module, compared to the Routing Layer in the conventional layered approach. Hence, integration of MAC into the Routing layer does not overload it. Instead, it helps in achieving easy routing. Thus, the integration complexity is compensated by easy routing.

4.2 Interfacing between Application layer and PHY layer

To survive till the end of the network life time, nodes usually conserve their energy by spending their time in sleep mode. Sleep mode is a state of a node where the node either hibernates or turns off its transceiver. It is observed that idle mode power consumption by the transceivers is not significantly less than the transmit or receive mode power consumption. Hence it is desirable to put transceivers to sleep mode instead of idle mode when they are inactive. But this requires a careful design to ensure that the power consumption during start up and time taken to start up the transceiver do not supersede the advantage of saving energy by moving the transceiver to sleep mode whenever they are inactive [56]. Now, through an interface Application layer can directly send signal to the physical layer to switch on the transceiver whenever data is going to get ready for transmission. Thus, saving the time taken to turn on transceiver, meanwhile Routing and MAC layers can focus on their functionalities. Another case where the direct interaction between Application and physical layer are advisable is during provision of certain security mechanisms. By sending hints directly to each other the physical layer and Application layer can save communication through routing and MAC layers.

4.3 Complexity Computation

Most of the science fields define the entropy as a degree of disorder or a degree of randomness in arrangement. Though, the definition sounds negative, it is worthy utilizing the concept in Cross Layer Design analysis to project the requirement of balance in complexity. Here, the entropy could be the random arrangement of layer interactions (cross layering), that deviate from standardization. As more number of deviations (random arrangement of layer interactions) grow, the system heads towards complexity. Similarly, as the layer interactions decrease, system heads towards idleness in cross layering becoming stagnant i.e., low performance.

Making an analogy with respect to the equations of system complexity based on the Paiva's [57] modelling, a method to measure the complexity of real systems, a rewriting of the expressions is as follows:

System complexity based on cross layer models,

$$\psi\ (\text{xlm}) = -\sum_{i=1}^{\rho} \text{p(xli)} \cdot \log_2 \text{p(xli)} \ldots\ldots \quad (1)$$

where ψ(xlm) is the system complexity based on cross layer models, p(xli) is the possibility of occurrence of the cross layer interactions. Assuming p(xli) equals to '$n_{\varepsilon i}$' in case of vertical calibration and p(xli) equals to $n_{\varepsilon i}$ -1 in case of interfaces and integration. While $n_{\varepsilon i}$ can range from 1 to n assuming n equals to 5, i.e. the number of communication software layers based on traditional reference models. Hence,

$$\text{p(xli)} = \{q \mid 1 <= q <= n\} \ldots\ldots \quad (2)$$

and ρ is the number of active interactions at the instant t, expressed by equation (3)

$$\rho = \sum_{i=1}^{k} n_{xli} . n_{\varepsilon i} \ldots\ldots \quad (3)$$

where k is the number of communication rounds. n_{xli} is the number of cross layer interactions per layer in each state, and $n_{\varepsilon i}$ is the number of layers involved in cross layering (taken from table.4).

4.4 System Analysis

Considering that the complexity ψ (xlm) , the type of cross layer interactions may be distinguished one from another by applying the relation R_{xlm}, expressed by

$$R_{\text{xlm}} = \frac{\text{performance in terms of data rate}}{\text{complexity}} \ldots \quad (4)$$

An optimal value of R_{xlm} indicates the suitable number of interactions for the system. In this, there is a measure that expresses the level of complexity in which the system achieves its goal with high performance. We denote this measure as natural complexity of the system, i.e., the proper level of system complexity. By using natural complexity as reference, the complexity decrease may mean that resources are becoming idle and the complexity increase may indicate that the system is overloaded and underperforming, as expressed by

Low Complexity tends to idleness

Natural Complexity tends to good performance

High Complexity tends to overload

The above computations determine the relation between the complexity and performance. Thus, indicating that lower complexity results in idleness or wastage of resources. The conventional Layered design is less complex and also it results in less output i.e. data rate, which may waste the duty cycles of the transceiver. Maintaining the complexity, if a cross layered model is designed like the proposed model HCLM, the performance of the system can be elevated. Care to be taken that the complexity does not overload the system which may result in the downfall of the performance.

5. CONCLUSION AND FUTURE WORK

The design of an efficient cross layer framework for Terrestrial and Underwater Wireless Sensor Networks to conserve energy & achieve low delay has become necessary as the ever-growing sensing & monitoring demands of Internet of Things (IoTs) applications has resulted in an explosive increase in deployment of self-configured and infrastructure-less wireless networks. In this regard, a detailed study on the design considerations and comparative analysis of Cross Layer approaches for Terrestrial & Underwater Wireless sensor networks carried out are presented in this paper, Further, deviating from the conventional approach of standardized layered system, this paper proposes a novel Hybrid Cross Layer Model (HCLM) which combines layer interaction through integration and interface to achieve a good performance across the system. The direction of the model is towards the enhancement of the performance with a trade-off between complexity and overload (or idleness). As most of the conventional functionalities of the layers have vanished, a higher layer can be made to directly interact with a lower layer through a simple interface and the middle layers can be integrated one into another to utilize the services more efficiently. Future work involves a building up of an efficient MAC layer to integrate into the Routing Layer.

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