HEC Startup Research Grant Program (SRGP) for Assistant Professors Joining under IPFP/TTS

FINAL PROGRESS REPORT *(Technical & Financial)*

Funding Agency: **The Higher Education Commission, Government of Pakistan**

HEC Award Letter No………1655……………………………………………………

[PI Name *(Dr. Moeenuddin Tariq)*]

[CoPI Name *(Dr. Fazli Subhan)*]

[Title of Research Project *(A link Reliable Routing Protocol for Underwater Sensor Networks)*]

[Name of Department *(Department of Computer Sciences)*]

[Name of University *(National University of Modern Languages)*]

Please ensure with the Report following Documents:

1. *Copies of Stock Register*
2. *Comments of HOD on Progress of Project*
3. *Completion Certificate (on last page of this Report)*
4. *Funds breakup as per award letter and Corresponding Utilization*
5. *Endorsement of University's resident Auditor*

Submit in confidence to Ms Uzma Naz – Deputy Director (R&D)

Research and Development Division, Higher Education Commission of Pakistan, Sector H-9, Islamabad

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2. RESEARCH PROJECT SUMMARY.

Principal Investigator (PI)	Dr. Moeenuddin Tariq
Co-Principal Investigator (CoPI)	Dr. Fazli Subhan
Title of the Research Project	A link reliable routing protocol for underwater sensor networks
Project Start Date	9th September 2017
Duration	8 months
Reporting Period	8 months
Approved Budget	351100
Department	Computer Science
University / Institute	National University of Modern Languages, Islamabad

3. INTRODUCTION

Underwater acoustic sensor network (UW-ASN) is an emerging area of research because of its applicability of monitoring, navigation, surveillance and tracking applications in various environmental, industrial and military domains. The increasing interest in these applications motivates research for development of underwater routing protocols in acoustic medium. Multiple underwater routing protocols have been proposed over the years that provide suitable low overhead mechanisms to sense, collect and transmit sensed information to onshore control systems. However, the intrinsic conditions in underwater environment raises many challenges for the design of reliable and efficient routing protocol. The motivation behind this research is to address the problem of high energy consumption in the information distribution phase, the problem of high end-to-end delay in route planning and data forwarding phase and finally the problem of enhancing network lifetime that has a significant effect on the performance of the network.

4. MATERIALS & METHODS USED.

PI and Co-PI have followed a research model to solve the undertaken research problem. PI and Co-PI have performed an extensive research and studied multiple research articles to find out the research gaps in previously proposed routing protocols. On the basis of gaps found in the previously proposed routing protocols, PI and Co-PI developed algorithms to overcome the identified problems in the benchmark protocols. The benchmark protocols were H^2-DAB [1] and A reliable and energy efficient routing protocol (R-ERP^2R) [2]. The functions within the algorithms are verified by sample inputs. The proposed protocol is known as Energy Efficient and link Reliable (E^2LR) routing protocol for underwater sensor networks.

5. EXPERIMENTS UNDERTAKEN.

Experiments were based on the simulation of proposed algorithms and were carried out in Aqua-Sim [3] simulator specifically designed for underwater scenarios. Aqua-Sim is event driven first packet level simulator introduced for underwater networks that allow to model protocol processing in detail. Also it preserve packet level detail such as sequence numbers, checksums and it allows easier interface with actual operational networks. Moreover, as packet-level simulators capture detailed network operations, it shows any behavior that can come up in a real network. Aqua-Sim offer channel modeling in a 3D environment with high acoustic delay, high transmission and physical attributes such as temperature and salinity. However, Aqua-Sim is confined to itself and does not affect CMU wireless or other packages and evolve independently. Moreover, it allows offers various built-in MAC protocols tailored specifically for the underwater networks and further allows integration of custom attenuation, channel models without affecting rest of Aqua-Sim functionality. In the simulation of E^2LR protocol, the channel model used in Aqua-Sim in *underwater channel class* considers the presented in [3,4]. Moreover, E^2LR considers grid and random topology for the simulation as shown in Figure 1 and Figure 2.

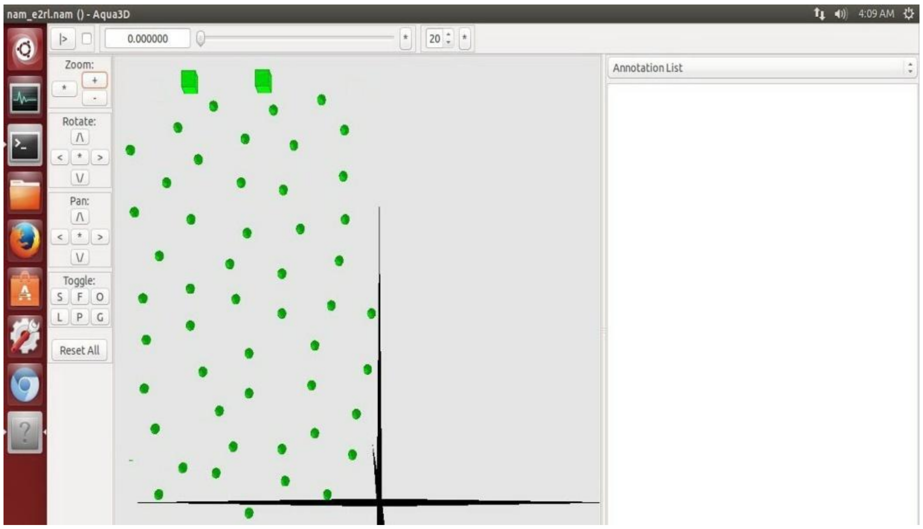

Figure 1. An example of random node deployment in Aqua-Sim

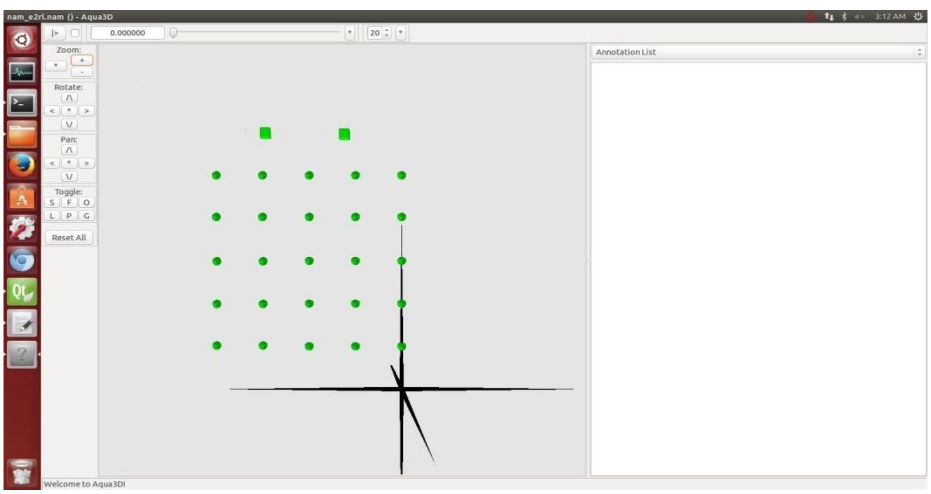

Figure 2. An example of grid node deployment in Aqua-Sim

In E^2LR, one or more sink nodes are deployed on water surface depending upon the scenario in both topologies. Multi-sink scenario not only allows for high delivery ratio but also decreases the energy consumption of the nodes closer to the sink that helps in maximizing network lifetime. A reference point is used for the nodes to know maximum distance. Similarly, one or more nodes are selected as source nodes for data transmission. Link quality information is checked with the different number of packets to set a minimum cost required to obtain proper information. The simulation parameters, medium access control (MAC) protocol, physical layer model considered for the performance evaluation of E^2LR protocol are presented in Table 1.

Table 1. Simulation parameters

Parameter Description	Notations	Values
Node Deployment Area	*Area*	1000x1000x1000
Simulation Time	T_{sim}	300s
Number of Nodes	N	25-400
Number of Sources	T_{sr}	1-3
Packet generation rate	T_{sr}	1 packet/s
Distance Threshold	T_d	70m-110m
Link Quality Threshold	T_lq	60-71.5 dbm
Weight Factors of Link Quality	α, β	0.9, 0.7
Initial Energy	E	255J
Sending Power	P_{sn}	0.6W
Receiving Power	P_{rv}	0.3W
Idle Power	P_{id}	1 mW or 1 e^{-6}W
Payload Size	P	50 bytes
Node Mobility Speed	*MS*	0-4 m/s
Communication Range	*CR*	200m
MAC		Underwater Broadcast MAC
Propagation Model		Underwater Propagation
Antenna Type		Omni Antenna
Transport Layer Protocol		UDP
Compared Routing Protocols		R-ERP^{2}R, H^2-DAB

6. SAMPLING & MEASUREMENTS.

Not Applicable

7. STATISTICAL ANALYSIS.

Not applicable

8. TABLES, GRAPHS & FIGURES.

1 byte	2 bytes	2 bytes	4 bytes	4 bytes
Flag (Packet Type)	**Sender ID**	**Residual Energy**	**Sender Distance to the Sink**	**Timestamp**

Figure 3. Hello packet format in E^{2}LR

1 byte	2 bytes	2 bytes	2 bytes	2 bytes	2 bytes	50 bytes
Flag (Packet Type)	**Source ID**	**Previous Hop ID**	**Next Hop ID**	**Sequence. No**	**Sender Residual Energy**	**Payload**

Figure 4. Data packet format in E^{2}LR

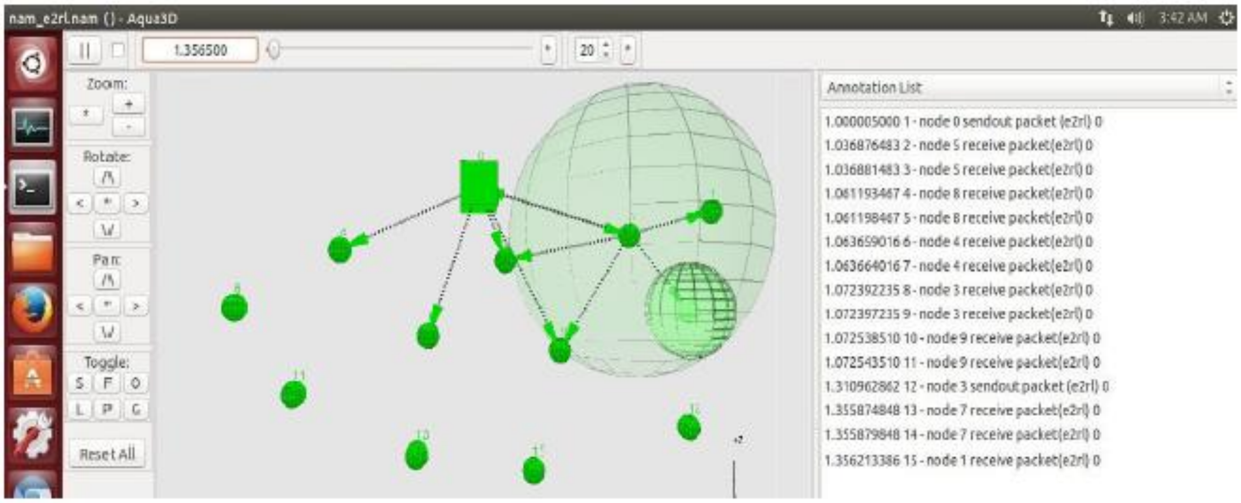

Figure 5. Process of ”Hello” packet distribution in E^2LR

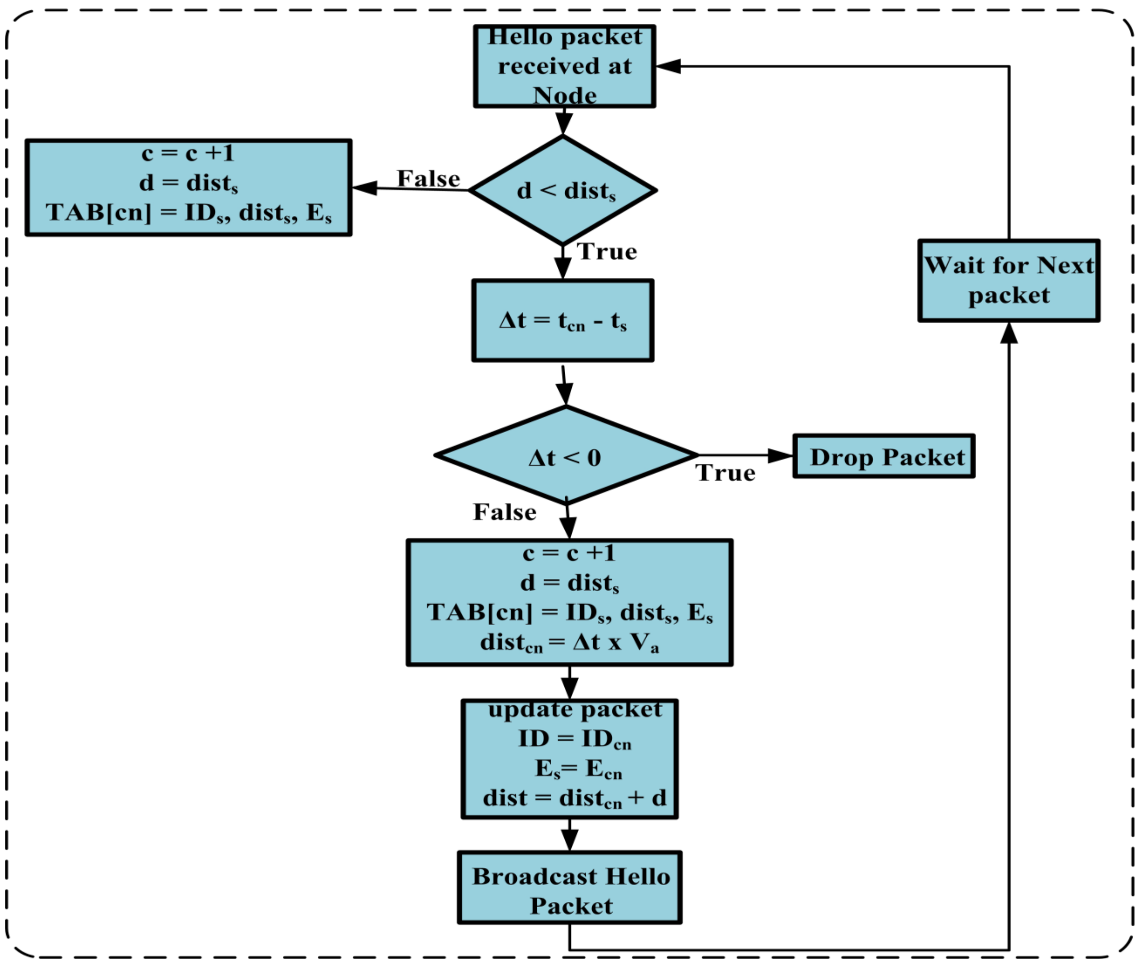

Figure 6. Flow diagram of distance calculation and information distribution in E^2LR

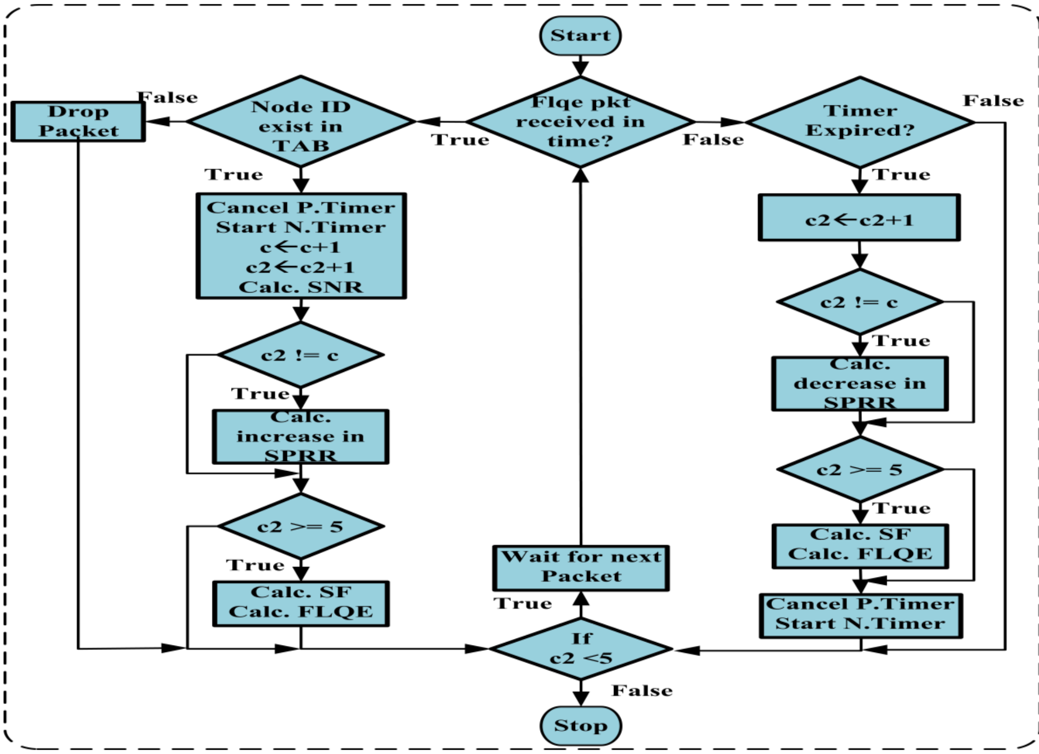

Figure 7. Flow diagram of link quality estimation in E²LR

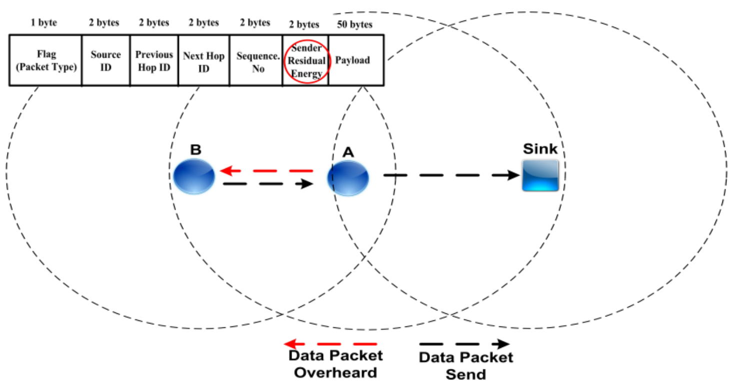

Figure 8. Updating neighbors with new energy status in E²LR

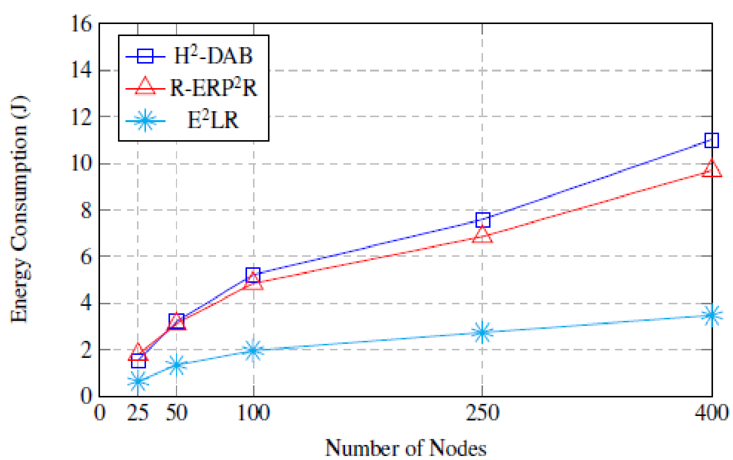

Figure 9. Energy Consumption in Information Distribution Phase (grid topology)

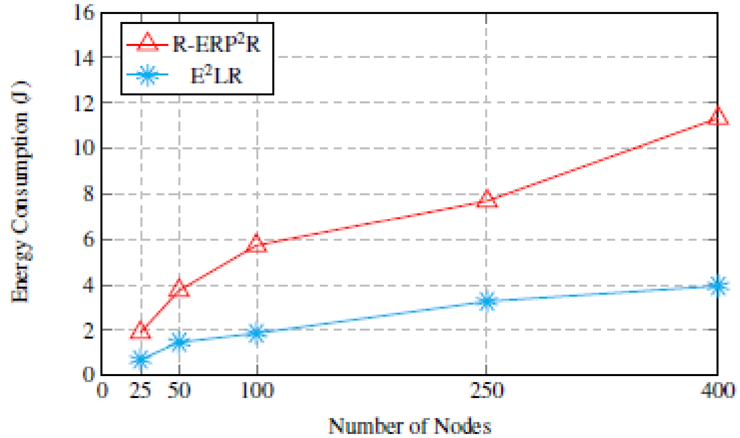

Figure 10. Energy Consumption in Information Distribution Phase (random topology)

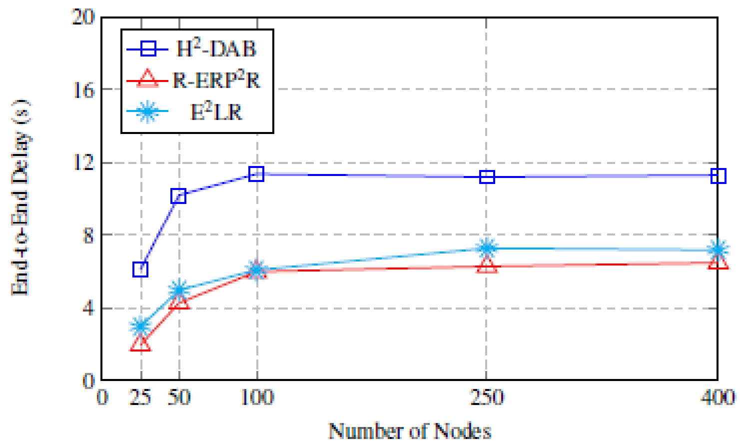

Figure 11. Comparing end-to-end delay (grid topology)

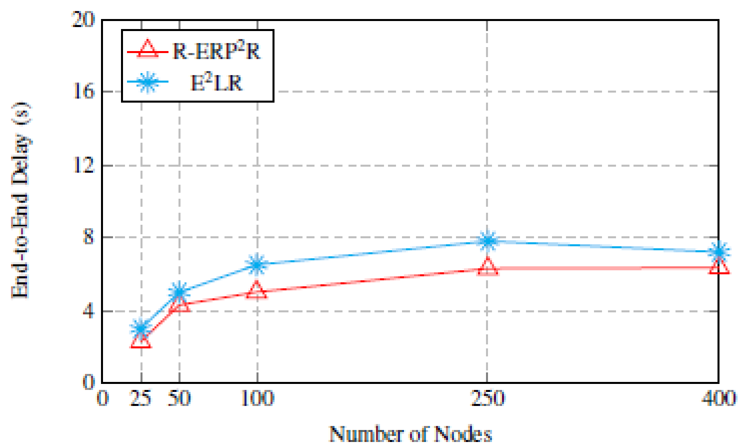

Figure 12. Comparing end-to-end delay (random topology)

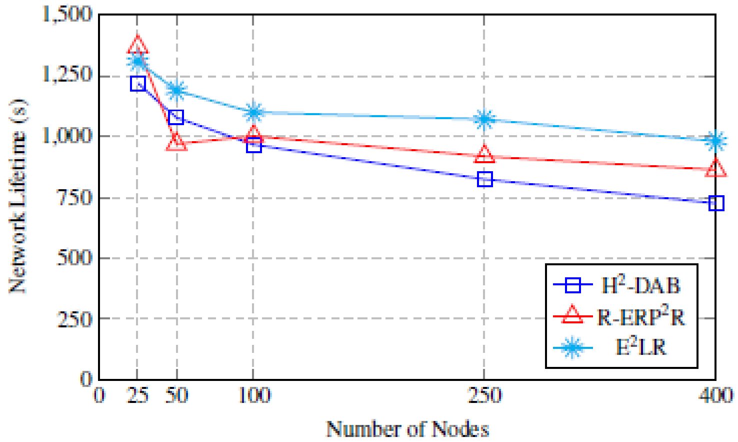

Figure 13. Comparing network lifetime (grid topology)

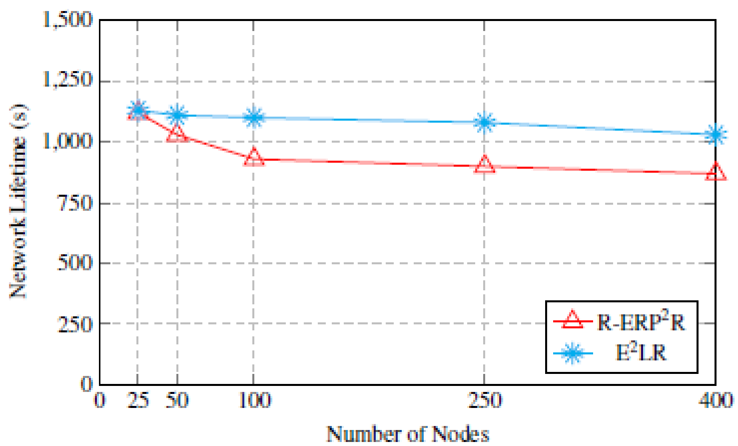

Figure 14. Comparing network lifetime (random topology)

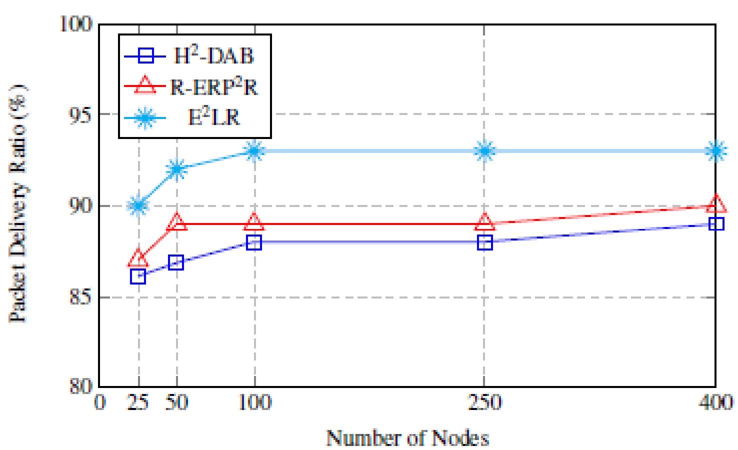

Figure 15. Comparing packet delivery ratio (grid topology)

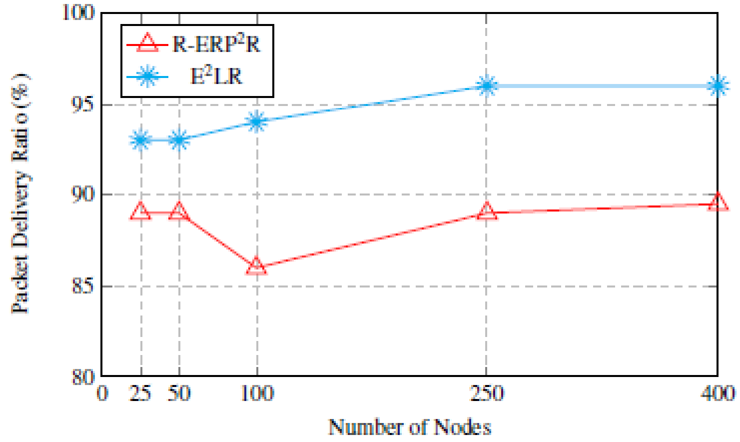

Figure 16. Comparing packet delivery ratio (random topology)

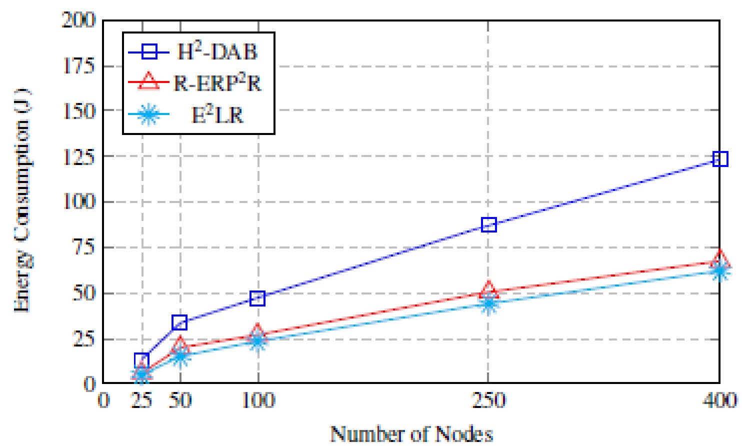

Figure 17. Comparing energy consumption in data forwarding phase (grid topology)

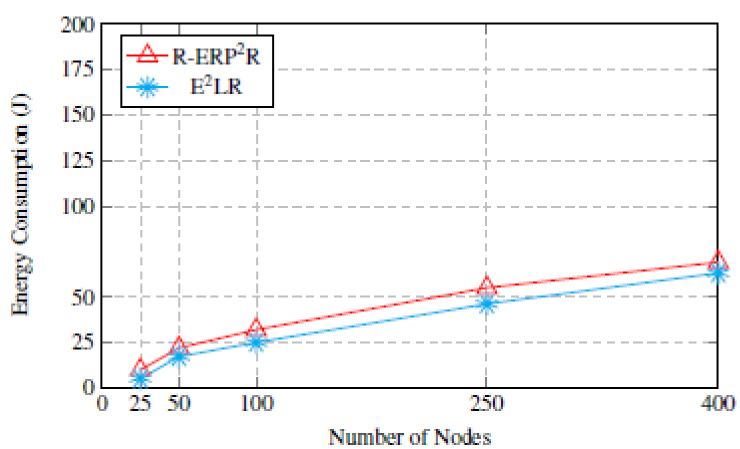

Figure 18. Comparing energy consumption in data forwarding phase (random topology)

9. RESULTS & DISCUSSIONS.

The energy consumption in the information distribution phase of the E^2LR protocol in comparison with R-ERP^{2}R and H^2-DAB in grid topology is shown in Figure 9. While Figure 10 does not contain graph for H^2-DAB, as it do not work in random topology. Therefore, it is not included in this random graph plot. In the process of information distribution, nodes in R-ERP2R forward every packet they have never received before to their next 1-hop neighbors. These includes packets that contains more physical distance than the one previously received. This is the reason the energy consumption in the information distribution phase of R-ERP2R is higher than the E^2LR. Nodes in R-ERP2R rebroadcast every packet they have not received preciously, to their next 1-hop neighbors. Another reason of higher energy consumption in information distribution phase of R-ERP2R is that it cannot avoid collisions that occur due to simultaneous transfer of data at the same time by two neighbor nodes. The result show that when the number of nodes are less such as 25-50, the difference between the two protocols is not much. However, when the number of nodes reach 400, E^2LR exhibits 179% and 187% higher energy efficiency than R-ERP2R in grid and random topologies respectively. On the other hand, H^2-DAB also pass down Hop ID information received from sink nodes in the whole network. The first path is two digit Hop ID is known as primary path. H^2-DAB also maintains a second path on receiving a Hop ID information from a second sink. It is also possible that a node may receive a new small Hop ID information from a third sink. Therefore, it has higher energy consumption as compared to both R-ERP^{2}R and E^2LR in the information distribution phase. The graph shows that with the increase in the number of nodes E^2LR attains a maximum higher energy efficiency gain of 216% than H^2-DAB in the information distribution phase in the grid topology.

For many underwater applications time is a strict requirement and data received after a specific time will be considered useless. Therefore, end-to-end delay plays an important role in delay sensitive applications. In the compared protocols, H^2-DAB suffers from highest end-to-end delay as shown in Figure 11. The primary reason that H^2-DAB suffers from higher delays is because it requires use of inquiry request and reply messages at each hop to search nodes with lowest Hop IDs. These inquiry is required to find a path and deliver data successfully to sink node. However, the average end-to-end delay remains almost same. This is because H^2-DAB works only with maximum of 9 layers. Therefore until and unless nodes are adjusted in less layers, the delay remains same. However, the increase in number of nodes does requires the use of more number of sinks. Figure 12 shows that when number of layers are 9, H^2-DAB has average delay of 11.2 seconds, which is higher than end-to-end delay E^2LR. The end-to-end delay of R-ERP^{2}R is depicted in Figure 11 and Figure 12. R-ERP2R exhibit delay of 2-4.5 seconds in the sparse network and has maximum delay of almost 7 seconds when the number of nodes are increased to 400. However, these results of R-ERP^{2}R are not based on DY-NAV 802.11, instead these results are on similar parameters with E^2LR i.e. underwater MAC protocol is used for the simulation of H^2-DAB. The default setting of R-ERP^{2}R using DY-NAV 802.11 will not allow it generate data at 1 packet/s. This is because DY-NAV 802.11 requires Request to Send (RTS) and Clear to Send (CTS) packets to be send before actual data forwarding [5]. This is the reason difference in end-to-end delay is not much between R-ERP^{2}R and E^2LR.

Network lifetime is an important parameter for long term projects. For nodes to perform different tasks in parallel for longer time requires balance in energy consumption of each node in the network. The capabilities of H^2-DAB, R-ERP^{2}R and E^2LR are summarized in Figure 13 and Figure 14. As per simulation results, nodes in H^2-DAB drain their battery faster than R-ERP^{2}R and E^2LR in both topologies. Fast battery drain in H^2-DAB is because, it does not implement any mechanism to maintain energy balance in the network. It always uses the node with lowest Hop ID. In the static network it will therefore exhibit worst network lifetime. Hence the repeated use of same nodes reduces the network lifetime. Increase in the number of source nodes also affects the lifetime of the network. Figure 13 shows that when the density of the network increases the lifetime of H^2-DAB decreases. Result show that when the number of nodes are increased to 400, H^2-DAB exhibit almost 25% less network lifetime than E^2LR. Similar to H^2-DAB, R-ERP^{2}R and E^2LR also implement a scheme where a single best node based on several metrics is selected for data forwarding. Therefore, they both avoid redundant data transmissions even in the dense network. However, R-ERP^{2}R selects cost based on link quality and residual energy, which means that it could select a node having a higher value of link quality but low energy. R-ERP^{2}R cost calculation metric allow it to choose low energy nodes and hence using same node over and over again results in short network lifetime. Moreover, ETX [6] overestimates the link and therefore retransmissions are inevitable. In Figure 13, a sudden fall in the R-ERP^{2}R graph shows exactly this phenomenon. E^{2}LR, on the other hand, not only prioritize a node by battery power but also only takes into account cost value above a pre-specified threshold. Hence, it selects a stable link at the next hop. Furthermore, E^{2}LR takes multiple metrics for link quality estimation, that allow it to select stable links. Result in Figure 13and Figure 14 shows that E^{2}LR exhibit highest performance gain of almost 13% and 18% over R-ERP^{2}R in grid and random topology respectively with 400 nodes. Therefore, E^{2}LR protocol demonstrates higher efficiency concerning network lifetime than R-ERP^{2}R and H^2-DAB.

Figure 15 and Figure 16 presents packet delivery ratio of all three protocols mentioned above in grid and random topology respectively. It can be observed that when number of nodes are 25, H^2-DAB exhibit packet delivery ratio of around 86% in both grid topology. This is because in sparse network, chances for availability of nodes at next hop are less due to the mobility of nodes. Moreover, H^2-DAB does not consider quality of the link in the selection of next hop, which also results in packet loss. However, with the increase in the number of nodes in the network, packet delivery ratio for H^2-DAB increases as well. Results show H^2-DAB successfully delivers 285 packets out of 320 generated packets in grid topology. In grid topology, the depth of nodes remains the same but distance between nodes changes with the mobility of nodes due to water current and hence performance of H^2-DAB declines, with the increase in mobility speed. R-ERP^{2}R demonstrate 87-89% delivery ratio in sparse network, almost same as H^2-DAB but as the network become dense R-ERP^{2}R achieves delivery ratio almost equal to H^2-DAB with lower communication cost. Routing protocols depend upon estimation of link quality to overcome low power unreliable links and to increase network efficiency in terms of packet delivery ratio, end-to-end delay. R-R-ERP^{2}R, utilize ETX metric which calculates packet receive ration to measure goodness of the link, which according to [2], helps in selection of reliable node at next hop. However, 1) ETX overestimates the link as it depends only upon packet receive ratio; as a result, poor links are selected as good links 2) as ETX exhibit poor performance with node mobility and PRR cannot be correctly estimated at times due to high mobility of the nodes. Therefore, fluctuations in the R-ERP^{2}R graph can be seen specifically in random topology. The simulation result show that when number of nodes are increased to 400, R-ERP^{2}R successfully delivers 287 and 289 packets out of 320 packets in grid and random topologies. This is because with the increase in the number of nodes, more candidates are available at next hop. However, because transient low performance links are declared as good by ETX [7], it exhibits low delivery ratio. E^{2}LR on the contrary, achieves data delivery ratio of above 96% and 94% in random and grid topologies respectively with less communication cost as compared to both H^2-DAB and R-ERP^{2}R. E^{2}LR successfully delivers 308 and 303 packets out of total send packets in both topologies. Metrics such as channel quality, stability and packet receive ratio play an important role in selection of single best next hop link together with physical distance. As single node selection protocol, E^{2}LR avoids data redundancy and a complete evaluation of the link by FLQE facilitate in selection of most reliable link among many candidate nodes at next hop.

The term energy efficient refers to the performance gain in the information distribution phase and in the data forwarding phase. This performance gain is achieved by reducing energy consumption in events such as transmission/reception of messages and number of retransmissions attempts [7]. The energy consumption of all three protocols is presented in Figure 17 and Figure 18. Energy consumption in H^2-DAB is higher than compared protocols due to poor next hop link selection, which requires H^2-DAB to send data packet multiple times before it successfully deliver to the destination. Another reason of higher delay in H^2-DAB is its handshaking method of data forwarding. Although H^2-DAB selects a single node at next hop but takes almost 2 times the energy consumed by compared protocols R-ERP^{2}R and E^{2}LR. The increase in the number of source nodes significantly affects the performance of H^2-DAB. In contrast, R-ERP^{2}R and E^{2}LR reduce the energy consumption caused by redundant transmissions and their performance is independent of total number of nodes. However, as ETX estimate only a single property of the given link, R-ERP^{2}R suffers from packet loss and retransmissions. In dense network E2LR has almost 7% higher delivery ratio than R-ERP^{2}R and H^2-DAB with 9% and 98% energy efficiency gain respectively. The graph in Figure 18 shows energy consumption of E^{2}LR as compared to R-ERP^{2}R in random topology. E^{2}LR has low energy consumption because it chooses next hop link by estimating multiple link quality metrics. On the other hand, R-ERP^{2}R only considers packet receive ratio for the selection of link quality for data forwarding. As a result, it requires more retransmissions attempts than E^{2}LR to deliver packet to next hop due to the selection of poor link. However, the difference shows small difference between the energy consumption of both protocols. This is because, the simulation of R- R-ERP^{2}R is carried out with Underwater MAC protocol. Had it been DY-NAV 802.11 as suggested by wahid et. al. in [2], then energy consumption will be very high due to the number of messages used in handshaking before data transmission [5].

10. CONCLUSION (in line with Proposed Outcomes).

In this research project we have developed a localization free underwater routing protocol E^{2}LR that considers the issue of higher energy consumption in information distribution phase, issue of higher end-to-end in data forwarding phase and network lifetime issue as. E^{2}LR reduces the energy consumption by its control flooding mechanism and enhance end-to-end delay by considering the link quality estimation. Simulation result shows that E^{2}LR achieves energy efficiency gain of 216% than H^2-DAB in grid topology and gain of 179% and 187% as compared to R-ERP^{2}R in random and grid topology respectively. E^{2}LR achieves higher packet delivery ratio of 96% with a similar end-to-end delay as R-ERP^{2}R. In grid topology, E^{2}LR improves packet delivery ratio by 7% over R-ERP^{2}R and H^2-DAB, with 9% and 98% less energy consumption respectively during data forwarding phase. Finally, E^{2}LR improves network lifetime by 13% and 25% compared to R-ERP^{2}R and H^2-DAB protocols respectively.

11. REFERENCES.

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[2] A.Wahid, S. Lee, D. Kim, A reliable and energy-efficient routing protocol for underwater wireless sensor networks, International Journal of Communication Systems 27 (10) (2014) 2048–2062.

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[6] D. S. De Couto, D. Aguayo, J. Bicket, R. Morris, A high-throughput path metric for multi-hop wireless routing, Wireless Networks 11 (4) (2005) 419–434.

[7] N. Baccour, A. Koubaa, L. Mottola, M. A. Zuniga, H. Youssef, C. A. Boano, M. Alves, Radio link quality estimation in wireless sensor networks: a survey, ACM Transactions on Sensor Networks (TOSN) 8 (4) (2012) 1–34.

Note: The references presented here are the references used in this form. The actual paper has 28 references.

12. LIST OF PUBLICATIONS.

1. Tariq, M., Tayyab, M., Subhan, F. and Ayaz, M. (2017). Energy Efficient and Link Reliable Routing Protocol for Underwater Sensor Networks. *Wireless Personal Communications (springer)*. Accepted since november 2017.

13. LIST OF PERMANENT EQUIPMENT PURCHASED UNDER THIS PROJECT (Also Mention the Name of Lab where Permanent Equipment are installed)

Desktop core i7, R&D LAB

14. MENTION NAME/DETAILS OF PRODUCTS DEVELOPED WITH THIS RESEARCH PROJECT

The research was to develop a routing protocol, which is not a tangible product. The name of routing protocol developed in this research project is "Energy Efficient and Link Reliable Routing (E2LR) Protocol for Underwater Sensor Networks"

15. LIST OF CHEMICHALS PURCHASED UNDER THIS PROJECT (ALONG WITH STOCK REGISTER ENTRY)

(Not Applicable as no chemicals were purchased)

12. AUDITED FINIANCIAL REPORT (PKR Millions). *In case of balance amount, a crossed cheque in favor of Director General (Finance), HEC Islamabad must accompany the financial report*.

Budget Head & Code	**Approved Budget (as per Award Letter)**	**Total Expenditure**	**Balance (If any)**
A: Salaries (Including Honorarium)			
B: Permanent Equipment			
C: Expendable Supplies			
D1: Literature, Documentation			
D2: Travel / Research & Training			
D3: Miscellaneous			
E: Indirect Cost (University Overheads)			
TOTAL			

Name of PI: **Dr. Moeenuddin Tariq** **Name of CoPI:** **Dr. Fazli Subhan**

Signature of PI: ______________________ **Signature of CoPI:** __________________________

Name of HoD: **Mr. M.Naveed Alam** **Signature of HoD:** __________________________

University/Institute Auditor's Verification:

Name: ______________________ **Signature:** ________________________________

STAMP