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Cross Layer Solution for QoS Guaranteed Efficient Transmission of Data in Underwater Wireless Sensor Networks

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Abstract: Communication in Underwater Wireless Sensor Networks (UWSN) itself sounds challenging and is complicated due to various issues like significant delay, latency, doppler effect, bandwidth limitaion and double side spreading. Thus ensuring energy efficient reliable transmission of data guarantee to achieve Quality of Service (QoS) for the same is the most important factor. This paper gives cross layer solution to transmit data with QoS energy efficient transmission for UWSN. The solution uses various parameters of network to optimize QoS, available bandwidth thus to calculate node selection score for reliable data transmission, at all different layers of Application, Session, Network, MAC, Physical layers. The solution involves estimation of dynamic link quality, awareness of congestion, physical switching, prediction and redundancy based coding, rate control based on QoS, adjustment in transmission range thus providing QoS guaranteed efficient data delivery for Underwater Sensor Networks.

Keywords: Error Control Code, Residual energy, Reed-Solomon, Route Desirability Factor, Super cluster.

I. INTRODUCTION

UWSN has higher research priority due to its challenging applications in underwater, that has been increasing the focus towards research. As radio signal in water environment has a very higher attenutaion, acoustic signals are being used for underwater communication and so is noted as Underwater Acoustic Sensor Network (UASN). Water current causes the movement of underwater sensors usually upto 2-3m/sec, with normal conditions and with different underwater activities it can move more than 5-8m/sec, thus resulting in variations in data rate and delay. Damages caused due to marine life as well due to oceanic salt water, the failure probabilty of sensor node is very high and inclusively replacement of battery also is not easy. Maintaining QoS under different service level application requirements also is equally important in UASN. This paper addresses all the above challenges by proposing a cross layer solution for energy efficiency as well QoS guarantee for underwater wireless sensor networks which is obtained by utilizing attributes of architecture of cross layer of IEEE 802.15.4 protocol stack by making use of error coding, transmission power control, selective multipath propagation and network topology adaptive routing. Additionally it adapts services of application layer by data rate adjustment of various applications which is dynamically based on present properties of network. The proposed work is being implemented in NS2 and is assessed for different constraints of UASN and is found that proposed solution results better when compared to existing works.

II. RELATED WORK

The survey is carried out for two categories of cross layer solutions and energy efficiency.

A. Cross Layer Solutions:

In [22] author has brought forward model for cross layer transmission which is on basis of IoT wireless adhoc network which decentralizes coded caching in the physical layer, content division multiplexing at MAC layer. This solution worked better only for particular traffic models of varying high and low traffic periods and also helps in reducing network congestion by reducing delay, but energy consumption wasn't taken into consideration. Xueyuan Su et al.[23] gave cross layer MAC for underwater acoustic networks that interacted with rate allocation scheme that was price based at network layer. In order to correctly show clique constraints of wireless medium, price that was clique based was theorized to perform as congestion signal, which controls multi hop flow's end-to-end rates. A cross layer MAC for underwater sensor networks was generalized by Xueyuan Su et al. [10], that interacted with rate allocation scheme based on price at the network layer. Then MAC protocol schedules transmission of packet without contention for a sole hop in individual maximum clique. In the need of extending networks life cycle, transmission power being optimized. Roberto Petroccia et al.[12], discussed on cross layer that is adaptive for Underwater Acoustic Networks that was fully distributed and self-adaptive, and the protocol supported cross layer information usage in order to interact with physical layer.

B. Efficient Data Transmission: (Energy efficiency)

Ye et al. [1] progressed fault tolerant routing protocol for WSN which was cluster basis for authentic data transmission. Firstly non-uniform multi layer clustered network topology was performed which prohibited inter cluster load imbalance problem. Later to perform selection of Cluster Head (CH), FIS model was being applied that quantified every node for the suitability of being CH. Grasielli et al. [3] inscribed communication issue that was energy efficient, that used optimized framework for channel coding, where in two layer encoding technique is taken into consideration inclusive of Forward Error Correction (FEC) codes as well Fountain Codes (FC) for UAN with no channels of feedback. Minimum consumption of energy necessity in underwater acoustic channel for the purpose of transmission of a single bit information was explored by De Souza et al. [5]. Rui Hou et al.[8] proposes an algorithm for Energy-balanced Unequal Layering Clustering (EULC) that improves acoustic sensors efficiency. The EULC designs unequal layering which is node depth dependent, provides solution to hot spot via cluster construction which varies in size in the same layer. Author has provided results that the energy is being balanced in nodes of UASN and also its life time is increased. Tayyaba Liaqat et al.[20] showed hybrid routing protocol which was on basis of Depth Energy Balance for UWSNs that selects neighbor node that has priority for the purpose of forwarding data from sink on depth basis. M. Aslam et al.[9] gave Energy Efficient logical Cubical layered Path Planning Algorithm (EECPPA) as well Multiple Sink EECPPA (MSEECPPA) for acoustic Underwater Sensor Network. Given models are pliable in variations of sensor location and thus have magnificent potential to reorganize logical cubes size within 3D cubical UWSNs and the cubes play crucial part in selection of Cluster Heads (CHs). MSEECPPA will select relaying nodes i.e multiple sinks in order to make use of multi-hoping technique thus increasing lifetime of long distanced nodes from Base Station (BS). De Souza et al.[16] probed least consumption of energy needed for transmission of single bit over acoustic channel. Considering, use of binary FSK modulation as well involutional error correcting codes they optimized operation frequency, SNR and code rate when target FER is being obtained. Fatma et al.[7] made an in depth study of effect of unique characteristics of underwater thus balancing energy consumption of underwater sensors. Researchers also came up with balanced routing strategy inclusively of deployment pattern that punctiliously regulates load weight in all possible next hop, that give rises to equal consumption of energy amidst all sensors thus improving network lifetime.

III. PROPOSED SOLUTION

Architecture of solution proposed is as below in Fig. 1.

Cross layer solution includes solutions at Physical, MAC, Link, Network, Session and Application layers in order to accomplish goals like increased packet delivery ratio, reduction in energy consumption and reduced delay for packets with higher priority.

A. Application Layer

Sampling rate of sensors is being controlled, inclusively control is made on outgoing flow of packets. On the basis of latency of routing path as well residual energy of node sampling rate is being controlled. Latency is given with respect to Round Trip Time (RTT/2). Computation of RTT is probability mass function with respect to distribution of delay as in Equation 1.

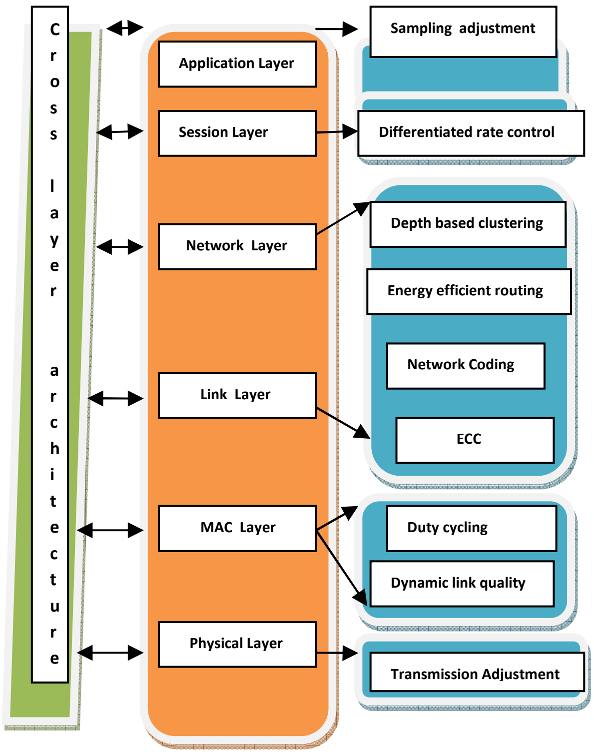

Fig: 1. Architecture of Cross Layer Solution

$$RTT = \begin{cases} \sum_{i=0}^{\infty} f_i(a).f_i(b) \;, x = 0 \\ \sum_{i=0}^{\infty} f_i(a).f_{2x+i}(b) + \sum_{i=0}^{\infty} f_i(b).f_{2x+i}(a), x > 0 \end{cases} \quad (1)$$

In which, ‘a’ is forward direction, ‘b’ is backward direction to receiver from transmitter as well f(z) is probability mass function in direction of z.

Each sensor node has N sampling levels from lowest 1 to highest N. The residual energy is split to two levels of safe(S) and not safe (NS). The current operational sampling level is on basis of latency and residual energy of the node as seen in Fig.2.

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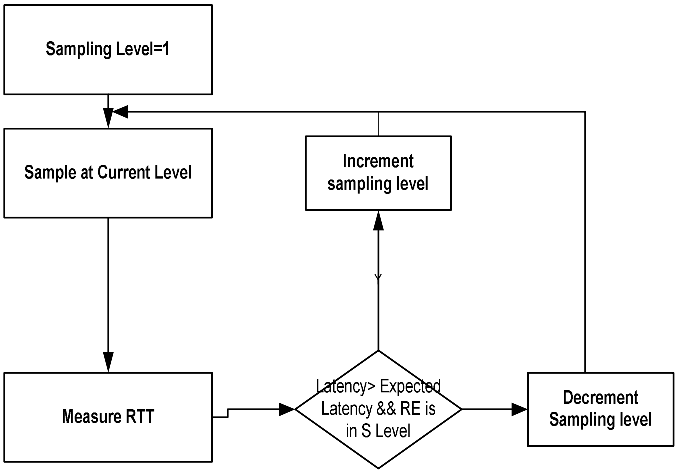

Fig: 2. Sampling Control

B. Session Layer

Services packets are being grouped as real as well non-real time flows prior to it gets pass to session layer. At every hop, depending upon type of service flow, the flow control is being made. Every relay node will compute traffic demand to relay packets from the neighbor nodes which allocates timeslots which commensurate to that of traffic demand as well packet priority and for every time frame, the process is being repeated at the start. A neighbor nodes, Future traffic Demand (FD) is computed as shown in Equation 2.

$$FD = \min(MA_i + D_i, T \times \Delta) \qquad (2)$$

In which, MA is the node's incoming traffic exponential moving average, D is buffer's traffic amount and T is present physical transmission rate. On the basis of priority intimation of packet received from application layer and traffic demand estimated, slots will be given dynamically for both real as well non- real time flow.

C. Network Layer

The clustering topology based on depth is being adopted in the Network layer as shown in Fig. 3, which has architecture of two level clustering done on basis of depth of node deployment.

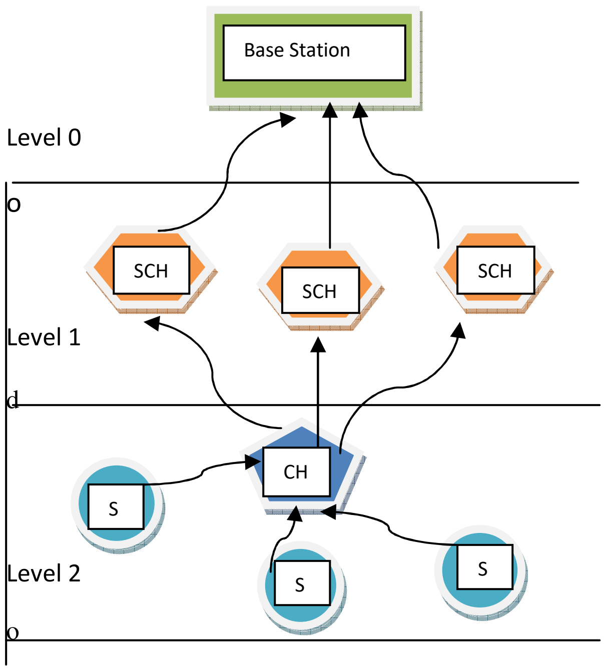

Fig. 3. Two Level Clustering Architecture

In the above figure SCH is Super Cluster Head, CH is Cluster Head and S is Sensor Node. Level 0 is Sink nodes. Level 1 is neighbor nodes which usually maintains relative position inspite of motion untill depth level 'd' from water surface as well energy above threshold called as Super Cluster Head (SCH). Level 2 is formed by rest of the nodes that do not exist either in Level 0 or in Level 1. Clustering is done on depth basis in Level 2 and the node having highest energy in it even at lower depth considered as CH. The nodes present at Level 1 are bidirectional and thus relay packets, whereas Level 2 has unidirectional nodes. The data is being sensed by nodes of Level 2 and are being transmited to its respective CH. Later CH will aggregate all the data packets received and will transmit that aggregated packets to the nearest SCH of Level 1, which inturn process network coding of the received packets from the CH and will send to the sink present in the surface. As turbulence is high in Level 1, network coding process helps in obtaining higher packet delivery ratio. Process of network coding is as follows. Data packet recived by SCH from various CH is mixed and that composite packet is being sent to base station. The process of decoding being done in order to recover the original packets, thus the redundant packets being dropped. For the reason of avoiding increase in number of packets to generate redundancy which do not use any extra consumption of energy a simple XOR network coding is made at SCHs. Before sending data to base station data of two different CHs are being XOR and inturn all packets received at base station is being XOR again in order to recover original data packets. The total number of SCH to which CH sends the data is being controlled on residual energy pesent in respective CH. Fig.3 shows flow of packets to sink from the node.

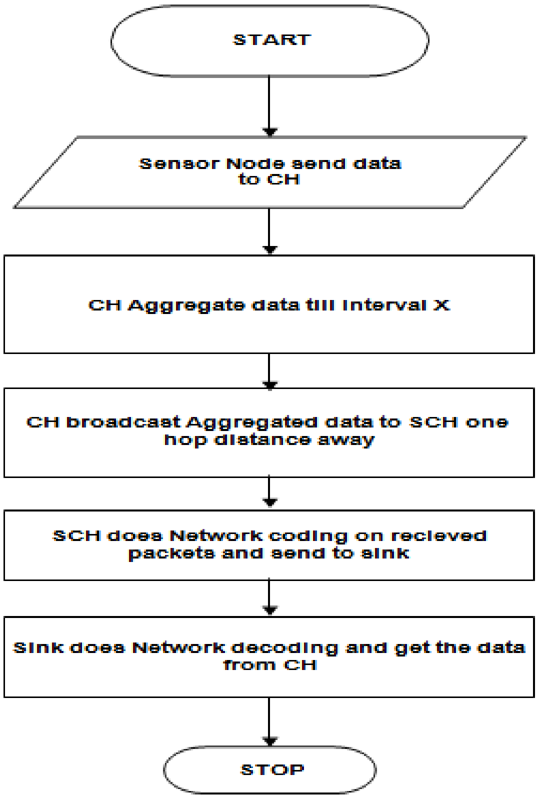

Fig. 4. Flow chart of forwarding algorithm

D. Link Layer

The usage of link layer for Error Control Code (ECC) is done in link layer, in order to give solution to issue of retransmission and thus wastage of energy by virtue of retransmissions. All sensor nodes, will send events sensed to CH using DPSK modulation in order to restore data in case of errors at CH without retransmission. ECC over the noisy channel provides finer Bit Error Rate (BER) performance for same or to lower Signal-to-Noise Ratio (SNR) when compared to uncoded system. RS (Reed Solomon) code is accepted as best selection for UWSN which has higher energy efficiency. Consumption of energy at node because of RS (n,k), in which 'n' is length of code, 'k' is number of information symbols is found and is seen that RS (31,26) has given better performance of BER thus with lower consumption of power. Thus RS (31,26) is made use for error correction to CH from the sensor node. QoS-Energy balanced routing is given at network layer that is constructed on top of AODV. With each route being constructed, Route Desirability Factor (RDF) is computed and path of routing having higher RDF is considered for the routing.

Computation of RDF is seen in Equation 3.

$$RDF = \alpha \times DF + (1-\alpha) \times RF \qquad (3)$$

In the above equation DF represents Delay Factor whereas RF represents Residual energy Factor.

AODV protocol is altered to assimiliate DF. Whenever RREP is being sent, every node will compute its part of DF and will add additional field DF to that RREP. Source node that originates RREQ, will select best RREP route having high values of DF and will use for forwarding packets. At every hop, RREQ forwarding length is being kept in control by configuring minimal value, such that to reduce control area of forwarding of RREQ, thus number of messages in network is decreased which leads to energy consumption reduction.

E. MAC Layer

Solutions adopted in MAC are duty cycling as well as dynamic link quality based data forwarding. For density based cluster which is generated, nodes are being allotted with duty cycle which is non-conflicting except CH node as exception. Time of duty cycle being allocated in proportion to node's residual energy. As UWSN has recurrent communication, the traditional centralized duty cycle decision is not acceptable. Thus a distributed duty cycle is proposed thus permitting every node to transmit data on basis of its individual residual energy as shown in Equation 4.

$$\tau = \frac{1}{1 - e^{-\gamma \frac{E_0}{E_i}}} \qquad (4)$$

In which

E_0 is node's initial energy, E_i is node's present residual energy and γ is parameter of performance tuning. Its noted that as energy level drops down, the transition probability also drops down.

Usage of Dynamic Link Quality parameter for sink selection by SCH amidst multitudinous sinks being made accessible. Every SCH will compute link quality of ratio of packet delivery atop of time by making use of Mean Exponentially Weighted Moving Average Algorithm seen in Equation 5.

$$\psi = \alpha * \psi + (1-\alpha) * DR \qquad (5)$$

In which α is gamut betwixt 0 to 1 and DR is ratio of packet delivery obtained in past interval. CH will compute link quality (ψ) for all sinks that are reachable and will opt that sink which has the value beyond the threshold.

F. Physical Layer

Adoption of solution in physical layer is the Transmission range adjustment for accomplishing forwarding of data along with energy efficiency. Transmission range is estimated as residual energy's weighted function as well node connectivity as shown in Equation 6.

$$T = w_1 \frac{1.25}{\sqrt{\rho}} + w_2 E_i \qquad (6)$$

Where $w_1 + w_2 = 1$ and ρ is node density, which is

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considered as total number of distinct hello broadcasts that is being received at node.

IV. RESULT AND DISCUSSION

The given solution is implemented in NS2. The following mentioned parameters were used during simulation.

a. Number of nodes : 50to250
b. Communication range :100m
c. Area of simulation : 1000m*1000m
d. Node distribution : Random distribution
e. Simulation time : 30 minutes
f. Queue length : 50
g. MAC : 802.11
h. Number of Base Station : 1
i. Location of BS : Moving on surface
j. Intial energy of nodes : 100 Joules
k. Motion of node: 2-5m throughout the center

Our work is being compared against [1] which is MNUC solution and [4] which is CMPS. The result is seen in regard of Packet Delivery ratio, Network overhead and Life time.

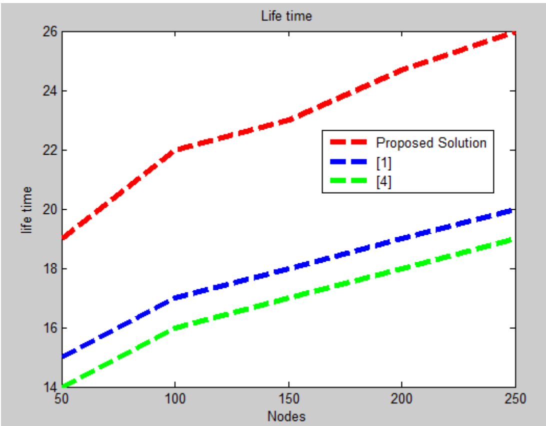

Fig. 5. Packet Delivery Ratio

Fig. 5 is ratio of delivery of packets of distinct nodes in all the three solutions. Ratio of packet delivery is computed by sensor nodes, which sends packets of CBR (Constant Bit Rate)=5 per second and thus computes ratio at sink. From results, ratio of delivery of packet is high in our work than [1] and [4].

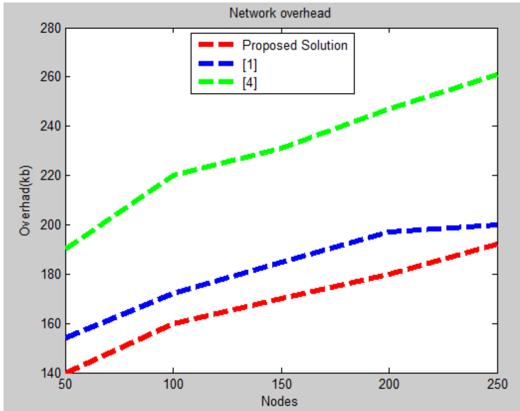

Fig. 6. Network Overhead

Fig. 6 relays overhead for various network nodes which is estimated in respect to total bytes and is passed on to network for a second. With above outcome overhead is quite low in our work than of [1] as well [4].

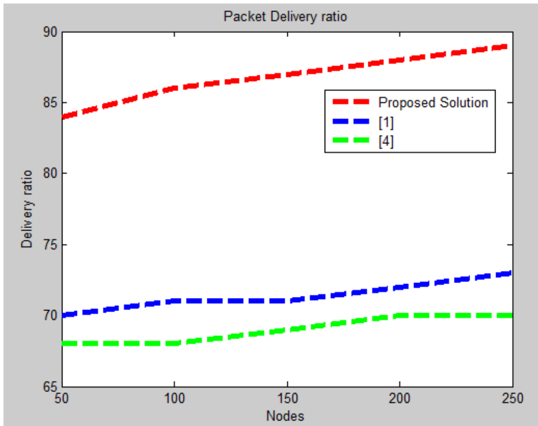

Fig. 7. Life time

Fig.7 is Life time estimated as time in which the first nodes energy becomes zero. From results, life time is high in our proposed solution than [1] and [4].

V. CONCLUSION

Underwater sensor nework plays major role in many alerting and monitoring systems. Thus reliability regarding higher delivery ratio of data packet as well as life time is of acute requirement and cross layer solution proposed ensures the same, with lower energy consumption. QoS guaranteed cross layer solution includes solution at Physical, MAC, Link, Network, Session and Application layers thus providing better efficiency. As solution inculcates network coding and error correction, the network avoids retransmission of data and also provides higher packet delivery ratio due to multipath transmission. QoS is improved as there is efficient selection of path directly on residual energy basis as well data control. Transmission power adjustment and duty cycling has noted lower consumption of energy and higher life time.

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