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Towards Energy Efficient Communication to Enhance Sustainability of Underwater Acoustic Sensor Networks

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Abstract— The emerging field of Computational Sustainability in Underwater Wireless Sensor Networks (UWSNs) focuses on the design of products, processes and services to satisfy the needs of large scale underwater applications. Ocean bottom sensor nodes can be used for oceanographic data collection, pollution monitoring, offshore exploration and tactical surveillance applications. With the dissemination of mobile devices with Internet connectivity, Oceanographers and marine ecologists who are mobile users can interact with underwater sensor networks to collect underwater data, anytime, anywhere using user-friendly mobile applications. The utility of UWSNs is far restricted by many theoretical or practical obstacles. Most underwater sensor nodes adopt un-rechargeable batteries with limited power supply. The wireless links among the sensor nodes appear to be unreliable and easily affected by various environmental factors. Nevertheless, there are hardly any fundamental results on the network capacity of duty-cycled UWSNs with unreliable wireless links. The sustainability of computing in the perspective of UWSNs relates to effective management of energy consumption, operating under energy constraints, and dealing with the environmental impact of electronic devices and systems. Our research addresses an energy efficient communication with a light weighted encoding technique called Lineage Encoding that overcomes the technical barriers of the large Scale UWSNs. The work is driven by the practice of autonomous interrogation of undersea data collected remotely for mobile environment. The simulation results portray the UWSNs to be sustainable under various network conditions.

Index Terms— Underwater Wireless Sensor Networks, Lineage Encoding, G-Node, Energy Consumption, Sustainability.

1 INTRODUCTION

A wireless sensor network (WSN) consists of a number of dedicated sensor nodes with sensing and computing capabilities, which can sense and monitor the physical parameters and transmit the collected data to a central location using wireless communication technologies. More than the 70% of the Earth's surface is covered with water (ocean and sea). New technologies have been developed to monitor and sense aquatic environments. Marine surveillance, river and sea pollution detection and monitoring, and oceanographic data collection are needed to explore, protect, and commercially exploit the aquatic environment. Underwater Wireless Sensor networks (UWSN) were developed to enable applications for oceanographic data collection, ocean sampling, environmental and pollution monitoring, offshore exploration, disaster prevention, tsunami and sea quake warning, assisted navigation, distributed tactical surveillance, and mine reconnaissance. There is, in fact, significant interest in monitoring aquatic environments for scientific, environmental, commercial, safety, and military reasons. The Underwater Acoustic Sensor Network has sensors that are deployed in an aquatic environment to perform collaborative monitoring tasks over a given region where the communication links are based on acoustic wireless technology. With the rapid development of mobile devices with internet connection, it is possible for the Oceanographers or marine ecologists know the underwater status by using their mobile which interacts with the underwater sensor network. This helps the marine ecologists to know the aquatic environment anytime, anywhere using a user friendly application in their mobile device.

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The main difference between Underwater Wireless Sensor Network (UWSN) and Terrestrial Wireless Network (WSN) are power and communication. More power is needed in case of UWSN when compared with WSN. Radio signals are used in WSN whereas acoustic signals are used in case of UWSN. Underwater communication cannot use radio signals because they have an enormous attenuation in the aquatic medium. Energy is the major issue in sensor network. As Underwater

Wireless Sensor Network consumes more power than a terrestrial sensor network, more energy efficient approaches have to be utilized in order to maintain a sustainable sensor network. The Battery power of the sensor is limited and usually batteries cannot be recharged also because solar energy cannot be exploited. With these entire energy crisis, when the information from the underwater sensor network reaches the mobile phones of the Oceanographers then there will be a huge loss of energy. This reduces the lifetime of the network, making the network fail in a short duration of time. In order to reduce the energy loss in the underwater sensor network and to develop a sustainable underwater sensor network this paper proposes a new energy efficient light weighted encoding technique called as Lineage Encoding which supports twig pattern queries.

2 Related Work

Energy is the major issue in UWSN as in Terrestrial Wireless Sensor Network. Park. Jun Pyo [1] proposed an encoding technique called Lineage encoding for energy efficient XML dissemination in Mobile Computing. This approach is found to be both energy and latency efficient. Considering the issues in sending the sensor values obtained from the Wireless Sensor Network using traditional SQL, the use of XML for broadcasting to the mobile device was proposed by Elias. A. G. F [10]. In SQL database the sensor values are available in the form of tables. Broadcasting the values from these tables to the mobile environment provides only the tabular form of content to the mobile user. But this is not in the case of using XML data. The sensor values from the SQL database is being parsed by the XML parser for the ease of mobile users. But there is a huge loss of energy of both client and server which should be focused. Since the acoustic links are un-reliable and the network lifetime reduces on transmitting sensed values from the base station to the mobile phones of the oceanographers and marine ecologists, a light weighted encoding technique called Lineage Encoding is proposed.

3 Water Quality Sensing and disseminating to Mobile users

As the human population growth and industry pressure in most developing countries continue to increase, effective water quality monitoring and evaluation has become critical for water resources management programs. The major parameters for water quality monitoring currently used by a wide range of government, educational and private agencies are Salinity and conductivity, Light, Dissolved Oxygen, Temperature, pH, Nutrients, Phytoplankton, Zooplankton and Aquatic Pathogens. In this paper, we focus on Salinity, Temperature and pH of the Marine environment and disseminate the sensed values to the mobile phones Marine Ecologists or Oceanographers.

In this section, we introduce a light weight encoding technique for obtaining the sensed parameters from Underwater Sensor Network to the mobile devices of the Oceanographers. First, we explain the architecture of our proposed work. Then, for a sample XML document Lineage code calculation is discussed. Finally, we describe the formation of G-Nodes which avoids irrelevant transmission of data in the network.

A. Architecture

In this section, we discuss about the major components used in the architecture as in Fig. 1. The main components involved are 1) Sensors to sense a major parameter like temperature, pH and Conductivity for knowing the salinity of the water, 2) Gateway is Surface Buoys that relay data from the underwater network to the end device (cell phones) and also to regulate the depth of each sensor node, 3) XML streaming and energy efficient query processing in mobile client.

In Fig. 1, Sensors are deployed for pollution monitoring where the main parameters to be considered for the same are Conductivity, Temperature and pH. These Sensor nodes are the key components of the Underwater Wireless Sensor Network. The sensor nodes communicate with one another by means of acoustic links. They are Duty-Cycled i.e. the sensor nodes remain in idle (sleep) mode until they have a sensed value ready to be sent through the acoustic links. The Sensor's are organized as a cluster, each with their respective Cluster Head (CH). All the needed parameters sensed are sent to the floating buoy by means of the acoustic links available from each of the CH in the UWSN.

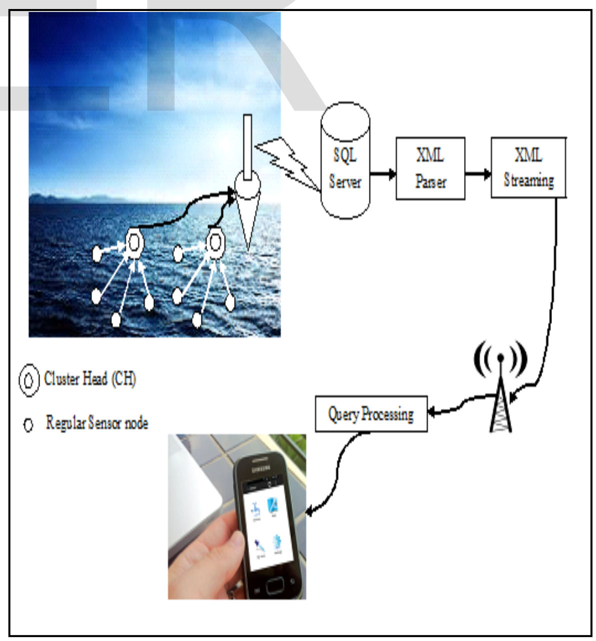

Fig 1 Architecture Diagram

Buoys are the gateways that relay the data from the UWSN to the respective device at the shore. These buoys are used to adjust the depth of each sensor node. The major components of the buoy are Wind Turbine, Lightening Conductor, Radar reflector, Solar panels, GPS and GSM antennas. Buoy may also have Fish Aggregating Device (FAD) to attract fish for monitoring their health, population, etc. Underwater Wire-

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less Sensor Network is mostly static. The Cluster Head has a wired connection with the buoy. The regular sensor nodes communicate to the cluster head by means of acoustic link. The CH is provided with greater initial energy since they cannot retain their energy by obtaining solar energy. The buoy having the solar panel can obtain energy from the solar energy. The regular sensor node communicates with its corresponding Cluster head by a simple TDMA method. The communications between them are done at regular time interval.

The Sensed data from the Underwater Acoustic environment to the shore is received by the base station and places them as raw data in the SQL server. All the collected values are retrieved from the SQL server by the XML parser which performs parsing operation on the raw data stored in it. Once the parsing operation is completed the streaming process is initiated which broadcast the Sensed values of the transmitting antenna's through which the sensor values reach the mobile phones of the respective Marine Ecologists or the Oceanographers respectively.

When the mobile client (Oceanographers) issues a query, selective tuning is done by which tunes to the appropriate broadcast channel and selectively downloads the XML stream for query processing. The XML Broadcasting is completed expeditiously in such the simplest way the server will support dynamic dissemination of a G-Node with a none interruption in Broadcasting. The broadcasted data stream will be in the form of G-Nodes with their corresponding calculated Lineage Code (V, H). This architecture supports dynamic broadcasting also. When the mobile client issues a query this proposed architecture can traverse the path from parent to child and from child to parent (Twig Pattern). This reduces the query processing time of the mobile client. Twig Pattern query processing is supported by the Lineage code generated. At the same time this architecture can support a massive number of mobile clients and thus achieves scalability in terms of service. And also with the formation of G-nodes, increase in the deployed sensor node for the same purpose can be supported which in turn achieves scalability in terms of network load. The sample XML document that is going to be parsed by the XML parser that is the running example in this paper is in Fig 2.

```
< UWSN>
  <Cluster1 id="01" name="C1">
    <Sensor id="011" name="S1">
      <Conductivity>2milliSiemens</Conductivity>
      <Temperature> 25° C <Temperature>
    </Sensor>
    <Sensor id="012" name "S2">
      <Conductivity>4milliSiemens</Conductivity>
      <pH> 7.8 </pH>
      <Temperature> 20°C </Temperature>
  </Cluster>
  <Cluster2 id="02" name="C2">
    <Sensor id="021" name="S3">
      <Conductivity>3.5milliSiemens</Conductivity>
      <pH> 8.3 </pH>
      <Temperature> 26° C <Temperature>
    </Sensor>
    <Sensor id="022" name ="S4">
      <Conductivity>4.9milliSiemens</Conductivity>
      <pH> 8.1 </pH>
      <Temperature> 29°C </Temperature>
    </Sensor>
    <Sensor id="023" name="S5">
      <pH> 8.0 </pH>
      <Temperature> 29°C </Temperature>
    </Sensor>
  </Cluster>
</UWSN>
```

Fig 2 Sample XML Document

B G-Node

The XML data stream in the wireless environment will be available in a sequence of integrated nodes, called G-node. It is a streaming unit that eliminates structural overheads of XML document and allows the mobile clients to skip downloading of unnecessary data during query processing. G-Nodes are streaming unit of a wireless XML stream. The G-node denoted by G_P =(GD_P, AVL_P, TL_P) is a data structure containing information of all the elements ep whose location path is p, where GD_P is a group descriptor of Gp, AVLp is a list containing all attribute values of e_P, and TL_P is a list containing all text contents of e_P.

In Fig 3 the structure of the G-node $_{Sensor}$ is shown Each G-node has three parts, namely a) Group Descriptor (GD) b) Attribute value list (AVL) c) Text List (TL). Group Descriptor is the collection of Node name, Location Path, Child Index, Lineage code, Attribute index and Text index. All these components of group descriptor are used to process XML queries in the client side effectively. Indices like CI, AI and TI are used to selectively download the next G-node, attribute values and Text.

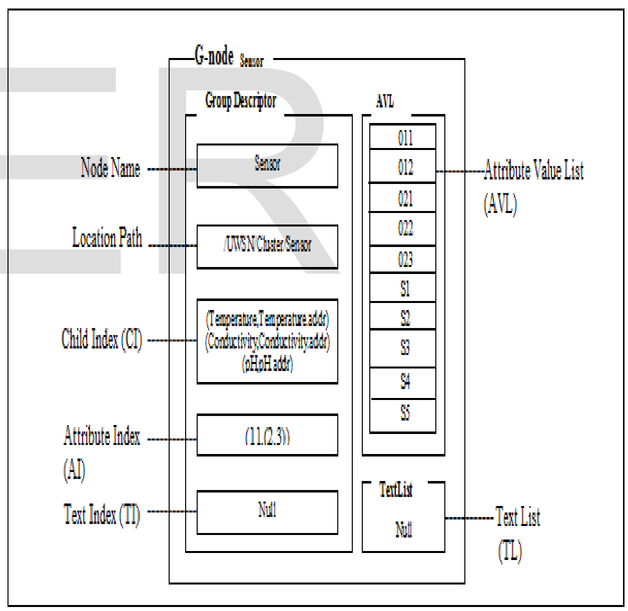

Fig 3 Structure of example G-node

C Lineage code

The Proposed novel encoding scheme called Lineage Code includes two types of Lineage age; i.e. Vertical code and the Horizontal code. The Vertical code is denoted by the Lineage code (V) and the Horizontal code is denoted by Lineage code (H). The main advantage of Lineage code generation is to represent the Parent-Child relationship between the G-Nodes. Fig 4 shows the lineage code in G-node $_{Sensor}$ and G-node $_{pH}$. Note that Lineage code (V) of G-node $_{Sensor}$ is defined by 11 since the elements integrated with G-node $_{Sensor}$ is mapped to first and second elements in G-node $_{Cluster}$. Lineage code (H) of G-node $_{Sensor}$ is (2,3) where each value denotes the number of child elements in G-node $_{Sensor}$ mapped to the same parent element in G-node $_{Cluster}$ in document order.

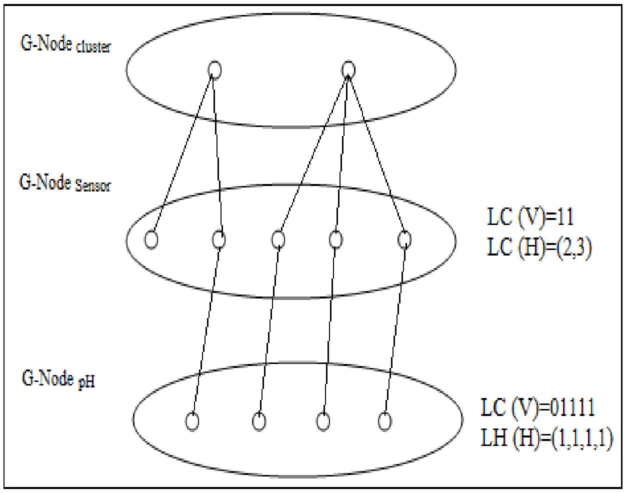

Fig 4 Lineage Code of G-node $_{Sensor}$ and G-node $_{pH}$.

4 Performance Evaluation

In the simulation environment 100 sensor nodes are deployed. The Sensor nodes are deployed in a random manner. The following results are obtained on experimenting with the NS2 Simulator. The initial energy of each sensor node and the cluster head is taken as 2.5 J and 5 J respectively. The proposed light weighted encoding technique, namely Lineage Encoding is compared with the LEACH protocol.

Fig 5, shows the average residual energy in the network after a certain round of transmission from the sensor network. The maximum available energy in the network with 100 nodes is 250 J. After 55 rounds of transmission the residual energy in the network with LEACH protocol is 20 J, whereas with the same round of transmission with Lineage Encoding, the network is found to have an average residual energy of 112 J. Therefore, the network with Lineage Encoding can maintain the network with maximum residual energy which influences the lifetime of the network.

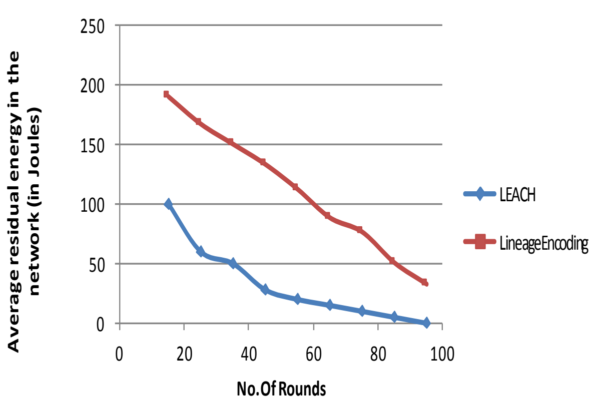

Fig 5 Average Residual Energy

Fig 6, shows the packet delivery ratio of both Lineage Encoding and standard benchmark (LEACH). The X-axis shows the number of packets transmitted and the Y-axis shows the Packet Delivery Ratio. On transmitting 80 Packets of the data, the delivery ratio of the packets to the receiver using LEACH protocol is 49%. On transmitting the same number of packets with Lineage Encoding the Packet Delivery Ratio is 81%. This makes clear that with Lineage Encoding reliable data transfer in the network is possible.

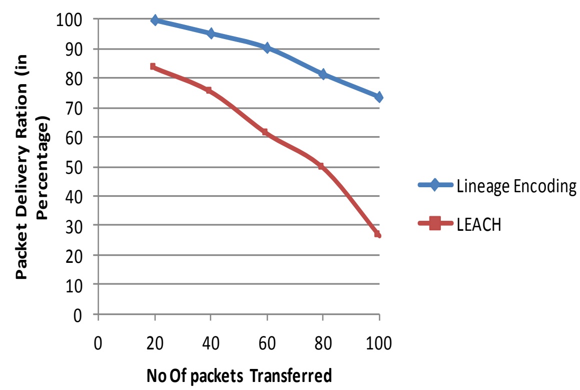

Fig 6 Packet Delivery Ratio

In this proposed approach, the Cluster Head is provided with maximum initial energy than the other general nodes. This is to overcome the energy constrain in the cluster head as they aggregate the sensed values and transmit them as G-Nodes. Fig 7, compares the available energy of the Cluster Head with LEACH protocol and Lineage Encoding on performing a series of transaction. Over 60% of transaction the energy of the Cluster Head will be reduced to 3 Joules from 5 Joules of its initial energy. Even after performing 60% of transactions the UWSN with Lineage Encoding will have 4.023 Joules of energy in the Cluster Head.

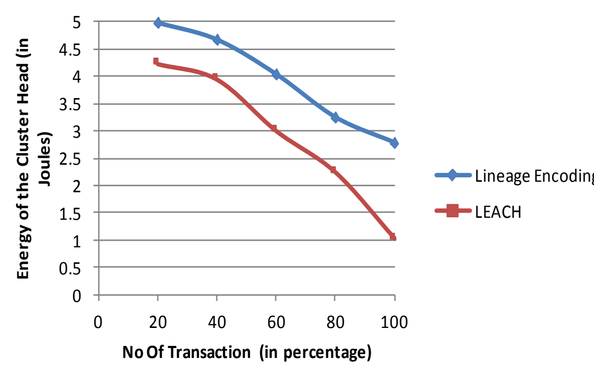

Fig 7 Energy of the Cluster Head

As the energy of the sensor nodes reduces with increase in time leads to the minimized coverage area of the network. The number of alive sensor node influences the coverage percentage of the UWSN. Fig 8, shows the coverage percentage of the network in increasing timestamp. As the time increases the sensor nodes will lose their energy leading to low coverage percentage. With Lineage encoding better coverage percentage of 95.7% is achieved on 3S whereas with LEACH protocol the coverage percentage is only 70.1%. As the energy of the sensor node is maintained at the optimum level with Lineage Encoding it shows a better coverage percentage than the network applying LEACH protocol.

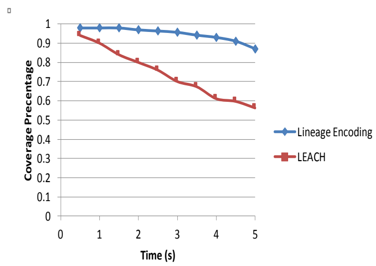

Fig 8 Coverage Percentage

5 Conclusion

The proposed energy efficient light weighted Lineage Encoding complements to overcome the technical barriers in the design of large Scale UWSNs. The paper clearly addresses the need to deploy underwater networks that ultimately enables real time monitoring of selected ocean areas, remote configuration and interaction with onshore human operators. This is made possible by connecting underwater instruments with wireless links based on acoustic communication. The work proves to overcome the key design challenges of underwater acoustic networks. The communication mechanism proposed, conforms to an efficient utilization of energy resources. Moreover, the Lineage Encoding technique capitalizes on the limited bandwidth available for communication in UWSNs. The communication model recommended, involves a concern to the channel characteristics, including long and variable propagation delays, multi-path and fading problems. Several simulations have been carried out to investigate the unique characteristics of the underwater acoustic communication channel, such as limited bandwidth capacity and variable delays, required for highly efficient and reliable data communication. Ultimately, the XML based encoding technique proves to ensure an energy efficient communication between onshore control systems and the monitoring instrument.

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