QoS Issues In Underwater Sensor Networks

Vivekanand Jha[1] ,Preeti Gupta[2] and Urvashi Ahuja[3]

Department of Computer Science Engineering
Indira Gandhi Institute of Technology
Guru Gobind Singh Indraprastha University, Delhi, India
[1]Vivekanand.iitm@gmail.com, [2]preetigupta1910@gmail.com,
[3]urvashi.ahuja17@gmail.com

Abstract

With the recent advancement in the field of communication, computation and underwater wireless multimedia sensor network, researchers have gained a keen interest in a new challenge; fulfilling the quality of service (QoS) requirements both from the applications perspective, ranging from industrial monitoring to disaster prevention and from the networks perspective. However, providing full QoS support to any application is a critical problem since sensor nodes are highly resource constrained and have unreliable and highly dynamic wireless links. The diversities in the operational environment and communication channel have significant effect on the underwater network, so additional QoS support is required for underwater wireless sensor networks (UWSNs) than wireless sensor networks (WSNs). In this paper, we have explored QoS challenges and perspectives for WSNs and UWSNs.

Keyword

QoS, QoS challenges, QoS perspectives, Underwater Sensor Networks

I. INTRODUCTION

Over two third of the planet is covered with water whose vast measures of potential have remained untouched. Recently as an attempt to explore this potential, many critical applications like oceanographic data collection, ocean sampling, disaster prevention, distributed tactical surveillance, pollution and environmental monitoring, offshore exploration assisted navigation and mine reconnaissance, have become the center of research in this area. These applications are broadly classified into two categories based on the time duration required, namely i) Long term Aquatic Monitoring (e.g. marine biology, oil/gas field monitoring, deep sea archaeology, seismic prediction etc.) and ii) Short term aquatic exploration (e.g. natural resource discovery, anti submarine mission, lost treasure discovery etc.). Underwater Sensor networks (UWSN) attempt to support a broad range of these applications, by deploying tiny mobile nodes with sensing, procession and communication capabilities.

Since it is a new area of research there is a need to define efficient communication protocols for underwater devices to make underwater applications feasible. As compared to the conventional

David C. Wyld, et al. (Eds): CCSEA, SEA, CLOUD, DKMP, CS & IT 05, pp. 45–51, 2012.

DOI : 10.5121/csit.2012.2206

terrestrial environment, the unique characteristics of the underwater scenario give birth to many new challenges, such as i) limited bandwidth capacity which is distance dependent and limited to few tens of kHz due to environmental noise at low frequencies and high transmission loss at high frequencies; ii) high propagation delays of the order of five orders of magnitude than in terrestrial challenges (due to low speed of sound); iii) multipath fading problems; iv) high bit error rate v) temporary loss of connectivity which leads to the formation of ‘shadow zones’ (where signal reception is impaired due to deep signal dips and fading caused by multipath); vi) node failure due to fouling and corrosion; vii) batteries are energy constrained and can not be recharged.[1]

In today’s developing times, having a system which performs a task is not enough; instead how efficient the system is in the given task, is of prime importance. A valuable return for the applied effort, both in terms of time and resources is needed. This is where Quality of Service (QoS) plays a crucial role. QoS is a widely used term defined as : ‘Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service’ as defined by International Telecommunication Union (ITU) Recommendation E.800 (09/08).

In context with the UWSNs there are numerous parameters which define the scope of QoS and are crucial deciding factors for underwater communication systems. QoS parameters are broadly classified into two categories, i) Application specific QoS parameters and ii) Network specific QoS parameters[2].

Application specific parameters focus on the quality demands of the specific task, for example camera resolution, jitter, delay, bandwidth etc for applications related to multimedia[3][4]; or quality of sensing, accuracy of capturing, reliable delivery etc for military or disaster prevention applications[5][6]. Number of active sensors and lifetime of the network are some other parameters of application domain.

Network specific parameters on the other hand focus on the service quality from the point of view of efficient resource utilization. Parameters such as resource constraint, node deployment, topological changes, energy depletion [7][8][9][10][11], data redundancy, multiple traffic types, real time traffic (Critical data), unbalanced traffic, scalability and congestion fall under this category.

In the rest of the paper we discuss how the above mentioned QoS parameters affect the UWSNs and various applications in this domain. Also we detail the previous work done in the field keeping a special focus on QoS.

II. QoS CHALLENGES

Ever since the inception of the concept of wireless sensor networks (WSNs) and their applications, one QoS parameter which has managed to gather maximum attention is the energy constraint. Since sensing vehicles are deployed deep inside the water surface, their batteries cannot harness solar energy hence are not rechargeable. Also replacement of these batteries is an impossible task due to node mobility which makes location and replacement of nodes expensive. Since both device and battery technologies have only recently matured to the point where micro sensor nodes are feasible, this is a fairly new field of study. Researchers have begun discussing not only the uses and challenges facing underwater sensor networks but have also been developing preliminary ideas as to how these networks should function as well as the appropriate low-energy architecture for the sensor nodes themselves.

Conventionally low energy adaptive clustering hierarchy-LEACH [7], based protocols have remained as a prime focus for energy conservation in wireless networks. LEACH is a randomized, adaptive, self configuring, cluster based protocol. By localized control for data transfers, it helps in reducing energy consumption. But LEACH also has various drawbacks. Though energy of many nodes is conserved, but that of cluster head is drained very rapidly due to overloading. Many improvements over this are proposed such as MIN-RC [8] which reduces overload energy consumption problem. MIN-RC uses a variable length round based on the minimum cluster size. I-LEACH [9] which focuses on cluster formation by removing nodes whose energy is lesser than some threshold value; EE-LEACH-MIMO [10] which works on the concept of cooperative multiple inputs and multiple output in a cluster; and LEACH-MF [11] adopts the method of multilayer clustering and eliminates redundant data; each of which aim at removing drawbacks of LEACH and thereby increase network lifetime.

A different approach of energy conservation was proposed by Clare et al. They developed a time division multiple-access (TDMA) MAC protocol for low-energy operation [27]. Using a TDMA approach saves energy by allowing the nodes to remain in the sleep state, with radios powered-down, for a long time.

Other major QoS factor of prime concern in the field of UWSN is related to nature of information being transferred and nature of the communication channel. This includes reliable data transfer, data redundancy, multiple traffic type, real time traffic and unbalanced traffic. [12] introduces the concept segmented data reliable transfer (SDRT), to achieve reliable data transfer in underwater sensor network scenarios. SDRT is essentially a hybrid approach of ARQ and FEC. It adopts efficient erasure codes, transferring encoded packets block by block and hop-by-hop. In SDRT, the data source first groups data packets into blocks. The data packets are delivered from the source to the destination block by block, and hop-by-hop. An intermediate node encodes each data block using an efficient erasure codes. When a receiver receives the encoded packets, it decodes and reconstructs the original block. After the reconstruction is done, the receiver encodes the block again and relays the block to the nodes in next hop. For each relay of a block, the sender keeps pumping encoded packets until receiving a positive feedback from next hop. This method aims at reducing the number of retransmissions using SVT coding scheme thereby improving channel utilization. Also it adopts the concept of window control mechanism to further reduce energy consumption. Also this paper focuses on reconstructing lost packets, not error correction within packets. In order to reconstruct the original data packets, the receiver has to receive sufficient encoded packets. Because the node mobility in underwater environment results in short communication time between any pair of sender and receiver, the transmission time for the encoded packets is limited. Thus, SDRT has to guarantee that the receiver can receive enough encoded packets in such a limited time interval. By setting the block size n (the number of original data packets in each block) appropriately, SDRT can control the transmission time and allow the receiver to be able to receive enough packets in order to reconstruct original block even in node motion.

Multipath routing [13] [14] ensures reliable transfer by introducing some redundancy, with multiple paths between source and the sink carrying same data packets. For applications in which reliable data transfer is of prime importance (e.g. military applications, disaster prevention and real time traffic) multipath algorithms serve better. In [13] original packets from various paths are combined at the sink node and erroneous packets are identified and replaced by error free packets from other path. In [14] route length and link lifetime is increased by introducing the concept of local backup paths in global multipath based on greedy forwarding mechanism. This results in improved data delivery.

Power of network coding is explored in [15] which help in increasing throughput, load balancing, increased data delivery ratio, effective utilization of bandwidth and deals with congestion and traffic. Apart from all these benefits, network coding also helps in energy conservation and better resource utilization. The core idea of network coding is to allow the mixing of data (e.g., by an XOR operation or a linear combination) at intermediate network nodes. Encoding packets at intermediate nodes and then sending only coded packet instead of individual packets reduces the traffic without increasing delay. In general, network coding is performed by encoding multiple packets either from the same user or from different users. The former is called intra-session network coding, while the latter is called inter-session network coding.

Concept of unbalanced traffic is handled in [16], where a counter is assigned to nodes which decide the number of transmissions that can occur in a row. After a certain interval of time, the counter is reset and the node is again available for transfer, until then other path is used.

Security is the key issue in [17][18][19]. Implicit security is proposed in [17], which introduces the concept of encrypt public key distribution and key management to ensure secure communication links. It uses hash functions and authenticated functions for key distribution. Different types of keys proposed are Single Network-Wide Key scheme, Fully Pairwise- Shared key scheme and Random Key Pre-Distribution Scheme. Protocol in [18] focuses on source to sink reliability of fragmented data packets. It incorporates acknowledgements and cache mechanisms to detect missing or erroneous packets. Protocol proposed in [19] is also based on key distributions to provide security.

Error discovery and correction is a crucial aspect of WSNs in order to increase efficiency and lifetime of the network. Due to interference in the underwater environment, error appears in the data packets during transmission. Error discovery can either be performed at the intermediate nodes ‘hop by hop’, which ensures timely error recovery and thereby removing excess traffic due to corrupt nodes. This method however drains the energy of intermediary nodes due to extensive error detection procedures. On similar ground, another way is to perform error discovery at the sink node called ‘end to end’ error discovery. Though this method conserves energy of all the intermediary nodes, but since error detection is delayed till the end, it may lead to high error rate making packet recovery more difficult.

Once discovered, error correction can be performed by either sending acknowledgement packets (ARQ), thus creating more traffic due to retransmissions, because ARQ-based schemes require the receiver to detect lost packets and then request the sender to retransmit packets. Other method is by using forward error correction (FEC) techniques, which aims at removing the concept of retransmission, by proactively adding redundant packets, so that the receiver (for hop-by-hop case) or the sink (for the end-to-end case) may successfully recover original packets. But this method requires more memory for data queues, hence introducing more delay. Another approach is of Hybrid ARQ, which uses negative acknowledgement. Sender then recodes the packet with a more effective FEC method.

Dario Pompili, et al., in [1] has focused on improving the efficiency of the network by limiting the packet error rate on each link along the path. This is done by introducing the concept 'short packet- train', where a channel once occupied is not released till all packets are transmitted. This reduces channel disturbance and hence reduces error in packets. FEC along with hybrid ARQ is used for error correction. Small size of packet improves channel efficiency, reduces energy consumption and reduces delay. The authors also investigate the delay-reliability trade-off for multihop underwater acoustic networks, and compare multi-hop versus single-hop routing strategies while considering the overall throughput. The analysis shows that increasing the number of hops improves both the achievable information rate and reliability. The authors provide a simple design example of a shallow water network where routes are established by a central manager based on neighborhood information gathered from all nodes by means of poll packets. The algorithm, however, does not consider applications with different requirements.

In [20] explores single path and multipath communication channels. Network coding is used for error recovery and to reduce energy consumption. Single path does not require error recovery or correction concepts because it is a simple forwarding mechanism, but for multipath communications both end to end and hop by hop FEC's are used in order to reduce number of retransmissions required. Optimization schemes are used by introducing sufficient redundancy and by choosing optimized paths in order to reduce energy consumption, reliable data transfer and efficient resource utilization.

After the successful researches in the wireless sensor networks, domain of research moved into a different direction with the shift in focus towards wireless sensor networks in underwater environment. Due to a difference in environment and communication channel, additional QoS-support is required besides QoS-support already explored in terrestrial networks.

Underwater (UW) channel show significant spatial and temporal differences. There is an increased propagation delay of five orders of magnitude (speed of acoustic signal is 1500m/s) than in the terrestrial wireless sensor networks (speed of radio signal is 3x108 m/s). Also sensor devices are more prone to corrosion and malfunctioning due to extremely harsh characteristics of underwater environment which decreases the network lifetime and level of reliability. In order to cope with these problems, derived QoS mechanisms must take extreme environmental conditions into account [2][20]. A few unique characteristics of UW are discussed next.

Higher Bit Error Rate is experienced in underwater networks, since the density of the medium is higher and the disturbances due to channel current persist. High density also leads to fading issues which in turn cause 'shadow zones'.

UW provides a 3-D environment, where the medium is in constant motion. As a result, node deployment (which is a very expensive task) becomes challenging. The deployed nodes which are free to float, lead to constant topological changes. New topology for each transmission demands highly dynamic neighbor discovery, path discovery, geographical information of the nodes and clustering. Few of these still remain open areas for research. Link failure, node malfunctioning and energy depletion are few other causes for changing topology.

UWSN is an upcoming area for research and so is the size of the network. Scalability is critical, since with increase in size of the network, area of observation increases, efficiency of the network may decrease and the original protocols designed may fail.

Bandwidth for UW environment decreases in comparison to that for terrestrial networks because the frequency of signals reduces. As mentioned earlier, bandwidth is distance dependent and topology of UWSN keeps changing. Hence there is a problem of limited bandwidth in UW environment.

There are numerous QoS routing strategies focusing on end-to-end delays in WSNs. With the arrival of wireless multimedia sensor networks, traffic can be composed of time sensitive packets and reliability-demanding packets. In such situations, some works also take into account link reliability to provide probabilistic QoS. The trade-off between the guarantee of the QoS requirements and the network lifetime remains an open issue, especially in large scale WSNs.
To date, all routing techniques address the QoS routing in terms of the end-to-end delay and reliability in small WSNs, made up of homogeneous nodes whose capabilities are almost identical. Furthermore, it seems that there is a need to address the same issues in large scale WSNs.

III. CONCLUSION

UWSN though inherit many properties from conventional terrestrial WSNs, but still it posses numerous unique properties. These new challenges such as reliable data transfer, data redundancy, unbalanced traffic, resource constraint and scalability. Performance of an underwater sensor network can be enhanced by minimizing end-to-end delay, minimizing collisions, maximizing reliability, minimizing energy consumptions, enhance adaptivity, minimizing interference and maximizing concurrency (parallel transmissions).

REFERENCES

[1] Dario Pompili, Tommaso Melodia and Ian F. Akyildiz "Distributed Routing Algorithms for Underwater Acoustic Sensor Networks" *IEEE transactions on Wireless Communications*, vol. 9, Sept 2010

[2] M. Aykut Yigitel , Ozlem Durmaz Incel, Cem Ersoy "QoS-aware MAC protocols for wireless sensor networks: A survey" *Elsevier, Computer Networks 55(2011)1982-2004*

[3] Luis Cobo, Alejandro Quintero, Samuel Pierre "Ant- Based Routing For Wireless Multimedia sensor Networks using Multiple QoS Metrices", *Elsevier Computer Networks 54(2010)2991-3010*

[4] P. Sarisaray-Boluk, V.C. Gungor, S. Baydere, A.E. Harmanci "Quality Aware Image Transmission Over Underwater Multimedia Sensor Networks" *Elsevier Ad Hoc Networks 9(2011)1287-1301*

[5] Jennifer Yick, Biswanath Mukherjee, Dipak Ghosal "Wireless Sensor Networks survey", *Elsevier, Computer Networks 52(2008) 2292-2330*

[6] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci "Wireless Sensor Networks: a survey" *Elsevier, Computer Networks,38(2002)393-422*

[7] Wendi B. Heinzelman, Anantha P. Chandrakasan,Hari Balakrishnan, "An Application-Specific Protocol Architecture for Wireless Microsensor Networks", *IEEE Transactions on Wireless Communications, VOL. 1, NO. 4, OCTOBER 2002*

[8] Ahmed Ghneimat, John Mellor and Ping Jiang, "Adaptive, Cluster Based, Sensor Network Routing Protocol", *UK Sim 13th International Conference on Modelling and Simulation, IEEE, 2011.*

[9] Naveen Kumar and Jasbeer Kaur, "Improved LEACH Protocol For Wireless Sensor Networks", *IEEE 978-1-4577-0321-8/11, 2011*

[10] Yongming Qin, Qiuling Tang, Ye Liang, Xiuyu Yue and Xian Li, "An Energy-Efficient Cooperative MIMO Scheme for Wireless Sensor Networks Based On Clustering", *IEEE 14th International Conference on Computational Science and Engg 978-0-7695-4477-9/11, 2011*

[11] Jian Feng Yan and Yuan Liu Liu, "Improved LEACH Routing Protocol For Large Scale Wireless Sensor Networks Routing", *IEEE 978-1-4244-6252-0/11, 2011*

[12] Peng Xie, Zhong Zhou , Zheng Peng, Jun-Hong Cui, Zhijie Shi "SDRT: A reliable data transport protocol for underwater sensor networks" *Elsevier, Ad Hoc Networks8(2010)708-722*

[13] Zhong Zhou, Zheng peng, Jun-Hong Cui, Zhijie Shi "Efficient Multipath Communication for Time critical Applications in Underwater Acoustic Sensor Networks" *IEEE/ACM Transactions on Networks, Vol 19 No. 1, Feb 2011*

[14] Wenjing Yang, Xinyu Yang, Shusen Yang, Dongxu Yang "A greedy-based stable multi-path routing protocol in mobile ad hoc networks" *Elsevier, Ad Hoc Networks 9(2011)662-674*

[15] Zhuo-qun Xia, Chao Liu, Xue-han Zhu, Pin-chao Liu, and Li-tong Xie, "An Optimization Multi-path Inter-Session Network Coding in Wireless Sensor Networks", *Springer-Verlag Berlin Heidelberg, 2011*

[16] Takeshi Murakami, lwao Sasase and Masaki Bandai, "Split Multi-Path Routing Protocol with Load Balancing Policy (SMR-LB) to Improve TCP Performance in Mobile Ad Hoc Networks", *2005 IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications.*

[17] Chien-Wen Chiang, Chih-Chung Lin, Ray-I Chang, "A New Scheme of Key Distribution using Implicit Security in Wireless Sensor Networks", *Feb. 7-10, 2010 ICACT 2010*

[18] Levente Buttyan and Lasz Csik, "Security Analysis of Reliable Transport Layer Protocols for Wireless Sensor Networks", *IEEE 978-1-4244-5328-3/10, 2010*

[19] Jooyoung Lee and Douglas R. Stinson, "Deterministic Key Predistribution Schemes for Distributed Sensor Networks", *Springer-Verlag Berlin Heidelberg 2005*

[20] Zheng Guo, Bing Wang, Peng Xie, Wei Zeng, Jun-Hong Cui, "Efficient error recovery with network coding in underwater sensor networks", *Elsevier, Ad Hoc Networks 7 (2009) 791–802*

[21] N. Xiong, L.T. Yang, Y. Yang, J.H. Park, G. Wei "Design of QoS in Intelligent Communication Environment Based on Neural Network" *Springer Wireless Pers Commun (2011)56:97-802*

[22] Min Liu, Shijun Xu, Siyi Sun "An Agent-Assisted Qos- Based Routing Algorithm for Wireless Sensor Networks" *Elsevier Journal of Network and Computer Application, 2011*

[23] Therence Houngbadji, Samuel Pierre "QoSNET: An Integrated QoS Network for Routing Protocols in Large Scale Wireless Sensor Networks" *Elsevier Computer Communications 33(2010)1334-1342*

[24] Hnin Yu Shwe, Fumiyuki Adachi, "Power Efficient Adaptive Network Coding in Wireless Sensor Networks", *IEEE ICC 2011 proceedings 978-1-61284-231-8/11*

[25] Zygmunt J. Haas, Tuan-Che Chen, "Cluster-based Cooperative Communication with Network Coding in Wireless Networks", *The 2010 Military Communications Conference,Waveforms and Signal Processing Track.*

[26] Tracey Ho,Muriel Médard,Ralf Koetter, David R. Karger, Michelle Effros, Jun Shi and Ben Leong, "A Random Linear Network Coding Approach to Multicast", *IEEE Transactions on Information Theory, vol. 52, no. 10, OCT 2006*

[27] Loren P. Clarea, Gregory J. Pottieb and Jonathan R. Agrea, "Self-Organizing Distributed Sensor Networks", *in Proc. SPIE Conf. Unattended Ground Sensor Technologies and Applications, vol. 3713, Orlando, FL, Apr. 1999, pp. 229–237*

[28] Liu Sheng, Qi Bing and Tang Laiangrui, "An Unequal Clustering Algorithm Based On Virtual Blocks For Wireless Sensor Networks", *IEEE Eight International Conference on Fuzzy Systems and Knowledge Discovery (FSKD) 978-1-61284-181-6/11, 2011*