Real-Time Traffic-Scheduling in Underwater Acoustic Wireless Sensor Networks

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Abstract. Underwater sensor networks are an important field of research. Several applications require the use of this kind of networks, like tsunami or oil spill alerts. The underwater medium is very harsh and only acoustic signals can be used for transmitting information. This kind of networks is still in development, far from reaching standard consensus on basic aspects like carrier frequency or modulation techniques. The use of these networks for real-time applications has not been analyzed previously. This paper summarizes [1], where we present two solutions for the scheduling of real-time messages and we provide a time constraint analysis of the network performance.

Keywords: Underwater Sensor Networks, Acoustic Sensor Networks, Environmental Monitoring

1 Introduction

Underwater acoustic wireless sensor networks (WSN) are becoming a hot research topic as they have turned into the primary tool to monitor and act upon the well-being of marine environments. Radio frequency electromagnetic signals do not propagate well underwater. Huge amount of power is required to transmit messages even for short distances. The presence of particles and moving obstacles like fish, prevents the use of optical carriers. For underwater transmissions, the best option are acoustic carriers. While WSN based on RF transmissions have been studied and several protocols have been proposed, the solutions achieved for them are not useful for acoustic underwater networks, since propagation delay is usually larger than transmission time. A message may be received well after its transmission has finished in the source node.

Real-time (RT) communications require not only that messages are transmitted properly, but also before a particular instant named deadline. If the deadline is missed, the message is not valid and may have serious consequences. A feasible RT schedule is one in which all messages comply with

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their deadlines. RT message scheduling in multi-hop networks is a complex problem that requires the use of routing and queueing techniques. If all the nodes in the network have a direct link to the rest of the nodes, the problem may be solved using an integer linear programming approach. However, when a message should go through intermediate nodes, it is not only a question of when a node should transmit (MAC problem) but also of selecting the appropriate path. In this case, the shortest path is not always the best one, as a per-node scheduling should be incorporated in the analysis. In fact, a node holding more than one message has to schedule their transmission introducing additional delays.

In this paper we extend the proposed algorithm presented in [2] to include RT constraints and message transfers between any pair of nodes in the system. A TDMA (Time Division Multiple Access) access protocol is proposed with an off-line allocation and scheduling algorithm. Feasibility conditions are given for the system to operate with hard RT constraints.

2 System Model

For the sake of simplicity, we assume the propagation delay between two nodes within transmission range is equal in both directions. Any node may transmit a message to any other node in the network if there is a valid path between both of them. We denote a message from node a to node b as m_{ab}. We also assume all messages require one time slot to be transmitted and that they are sent periodically. Additionally, all messages should be received before the associated deadline. P_{ab} and D_{ab} represent the period and deadline respectively. In general we define $Z = \{m_{ij}(P_{ij}, D_{ij})\}$.

The network can be modeled as a directed graph $G = (V, E)$, in which V is the set of nodes in the network and E the set of edges. If two nodes u and v are within transmission range, there is an edge connecting them, $e = (u, v)$. Each edge has a label that represents the transmission delay between the nodes measured in time slots, τ_{uv}. As collisions are important only if they are produced at the node, there are four different scenarios, as stated in [3].

We propose a slot allocation method to order the access of the nodes to the channel in such a way that each message originated in a node may reach its destination node without collisions. We begin considering that destination nodes are within transmission range of source/transmission node, and later we extend the analysis for nodes at larger distances. Stated in this way, the slot assignment problem is an extension of the graph coloring problem. We present an integer linear programming (ILP) model, to minimize the frame length measured in slots. The model is significantly more complex if a per message slot allocation is performed. Further details can be found in [3].

3 Scheduling

Path discovery is a well known problem in networking. Several algorithms have been proposed to compute the best path for a message to reach destination from a source. The most common solutions are based on Dijsktra algorithm to determine the shortest path from any node in the network to any other node (SPF, shortest path first). In the case of communication networks, the cost associated to the edges may be related to the actual delay between the nodes, an economical cost for using that link (paying service to a third party company) or the power required to use the link. For real-time messages, the total delay in the path should be less or equal to the deadline of the message. If this condition is not guaranteed, the message is not schedulable and the network does not comply the real-time requirements.

4 Heuristic approach

In the proposed model, the variables that affect the communication speed and therefore the timing of the system are the frame duration, the order of transmissions and reception of messages, and the routes that each message follows within the network. In section 5 of [1] an heuristic algorithm is presented to optimize the message/slot allocation to minimize the frame size and guarantee the deadlines. The minimum length frame is not necessarily the optimal to meet the system time requirements and this impedes uncoupling the calculation of the frame with respect to the calculation of routes. The heuristic presented generates a fixed length frame and optimize the paths of the messages to meet all system deadlines. This heuristic is better suited for complex problems where exists multiple paths for different messages.

5 Real-time applications

Tsunamis are generated by earthquakes in the ocean, and can be tragic like the ones in Japan 2011 or Indonesia 2004. While in the case of Japan, the number of casualties associated to the tsunami is relatively low, in the case of Indonesia, the number of victims is counted in thousands (and severe economic loses in infrastructure). The difference in the number of victims is associated to the early alert that people in Japan received to get into a safe place.

Detecting a tsunami is a hard work. Seismic sensors may be deployed in the area in which the earthquake may take place (geologic fault) and if this is detected, depending on the intensity a tsunami alert may be issued. The time available between the earthquake and the arrival of the wave to the beach depends on the distance to the earthquake epicenter. However, it is clear that there is a hard RT restriction as the alert should be issued with enough time for people to move into a safe place.

The system may have some buoys anchored along the fault and linked to the seismic sensors so once the earthquake is detected, the buoy connects through a satellite network to a management disaster office reporting the event, intensity and tsunami probability. However, buoys are vandalized by pirates or even fishermen jeopardizing the network operation. To avoid this, an underwater acoustic WSN is proposed operating in RT. The network deployment, nodes distribution and number of hops discussion is out of the scope of this paper. However, the RT analysis and network performance modeling proposed here can be used to set-up the appropriate network.

6 Conclusions and Future Work

We presented a RT analysis for an underwater acoustic WSN, with two approaches. First, the network is analyzed with integer linear programming techniques. SPF is used as routing policy combined with a message or node slot allocation procedure in a TDMA frame. We presented the schedulability condition for the case in which messages are transmitted following a FIFO policy. This scheduling discipline is quite simple and requires little processing within the underwater nodes. However, better results may be obtained if some RT priority policies are implemented (as future work). The second solution is based on a heuristic approach. Messages are scheduled following a per-link approach and finding the route with lower delay. This solution improves the 2-step approach of finding the SPF first, for allocating the slots within the frame later. As the heuristic only considers the messages actually being transmitted, unnecessary restrictions are avoided. We also presented a real application (tsunami early alert) in which RT transmissions are necessary.

Acknowledgement. This work has been partially supported by the Spanish MCI and FEDER funds of the EU under contracts TIN2013-44375-R, TIN2013-47245-C2-1-R, TIN2013-47245-C2-2-R, and also the Community Networks Testbed for the Future Internet (CONFINE) project: FP7-288535.

References

[1] R. Santos, J. Orozco, M. Micheletto, S.F. Ochoa, R. Meseguer, P. Millán, C. Molina. Scheduling Real-Time Traffic in Underwater Acoustic Wireless Sensor Networks. *Submitted to UCAmI'16*, Spain, 2016.

[2] R. Santos, J. Orozco, S.F. Ochoa, R. Meseguer, G. Eggly. A MAC Protocol for Underwater Sensors Networks. *Ubiquitous Computing and Ambient Intelligence. Sensing, Processing, and Using Environmental Information*, vol. 9454,2015.

[3] Y. Guan, C.C. Shen, J. Yackoski. Mac scheduling for high throughput underwater acoustic networks. *Wireless Communications and Networking Conference*, 2011.