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Cost Effective Smart System for Water Pollution Control with Underwater Wireless Sensor Networks: A Simulation Study

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The underwater sensor network is a rapidly developing area of research with a wide range of applications such as data collection in the ocean, pollution monitoring, and ocean sampling. One of the most researched areas is the coverage of underwater sensor networks, which are the basis of many applications. The coverage is usually related to how effectively a network is monitored by the sensor. There are major problems in the ocean or marine region, especially in water pollution. Underwater pollution generally causes acidification, plastic residues, and toxins. Today, the determination of this pollution is carried out through a human surveillance monitoring process. Therefore, there is a need for an automatic and intelligent monitoring system to identify the formation of pollution. The proposed simulation model defines the intelligent sensor-based monitoring system that identifies and alarms the formation of underwater pollution. Aloha was chosen as the medium access protocol for the cost-effective system in which we designed the simulation model. The efficiency of the system has been shown to be more stable, cost-effective and manageable than the monitoring process involving the existing human surveillance by testing with the simulation model.

Keywords: Medium Access; Pollution control; Sensor networks; Underwater.

1. INTRODUCTION

Since the mid-1990s, the terrestrial wireless sensor network has been rapidly evolving [1, 2]. However, the development of the underwater sensor network, limited by certain features of the underwater acoustic channel, such as limited bandwidth and wide propagation delays, the extension of the terrestrial wireless sensor network in the ocean application lags behind the terrestrial wireless sensors [3, 4]. The medium access control method of the current underwater sensor network is based on the relatively low-efficiency collision avoidance multiple access protocol and the Aloha protocol which is reliable to meet practical needs [5, 6]. Furthermore, in the case of heavy network load, the packet collision further increases the power consumption and distortion in network performance [7, 8]. Moreover, since ocean-based devices are usually powered by the battery, the power consumption of a single node is directly related to the lifetime of the entire network [9]. Therefore, the design of low power node architecture and low power medium access control protocol is the most important point in recent researches [10, 11]. Synchronous medium access technique protocol based on the sensor medium access control protocol is proposed as the standard for sensor networks [12, 13]. It operates in a sleep-awake mode to reduce power consumption and provides propagation synchronization between each node to prevent packet collision [14]. In addition, different medium access techniques are recommended to reduce power consumption [15]. However, in these techniques, it is necessary to use a special, ultra-low-power receiver to evoke the node [16].

However, many hardware architectures of the sensor network node does not have general use for a particular application

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[17, 18]. Therefore, the researchers lack a unified platform to test the practical performance of the protocols of medium access techniques of existing underwater sensor networks [19, 20]. Although the method of using universal equipment to test the performance of point-to-point communication within the underwater sensor network has been proposed as a reference, its energy consumption is slightly higher than expected by researchers [21].

Wahid et al. proposed a link-based routing protocol for underwater wireless sensor networks [20]. In the protocol they proposed, due to high error rates in the sensor networks, they addressed the issue of reliability. Therefore, they select a node that has the strongest link with the target during transmission as the next routing node. Using the NS-2 simulator, they compared the proposed protocol with the non-local routing protocol. With the results of the simulation, they emphasize that the proposed protocol shows more performance improvement [20].

Yu et al. investigated the sensor localization technique in underwater wireless sensor networks for underwater environments [18]. In underwater environments, they emphasized that the radio frequency signal is not suitable for underwater use due to the extremely limited spread. Therefore, underwater sensor networks need to be constructed with acoustic modems. Therefore, they needed a new localization algorithm to determine the position of each sensor. First, they examined the localization techniques for terrestrial environments. Then they presented the appropriate algorithm for underwater use. Finally, they evaluated the underwater based localization algorithm using different conditions between the communication range of the sensor node, the number of nodes and the position of the reference node [18].

Because low energy, high speed, and low cost are a prerequisite for underwater sensor networks, Byeon et al. have designed and implemented an underwater modem using a general-purpose waterproof sensor in their work [12]. They have also carried out some experiments in a water tank containing two point-to-point modems. According to their experiments, they emphasize that almost error-free communication is possible at a distance of 1 meter with a data rate of 1 kbps. However, with the increase in the data rate, the quality of communication has been rapidly deteriorated [12].

Katti et al. examined different sensor setup schemes and their impact on the coverage area [22]. They compared triangular, grid and hexagonal based sensor placement schemes for maximum coverage. Accordingly, they calculated the number of sensor nodes required in each case to achieve the desired coverage area [22].

The proposed simulation model defines the intelligent sensor-based monitoring system that identifies and alarms the formation of underwater pollution. Aloha was chosen as the medium access protocol for cost-efficient and low power consumption in the system we designed the simulation model. Based on the concept of software radio technology, this design and architecture work in a sleep-awake mode to ensure both generality and low power consumption. Riverbed Modeler and MATLAB software were used for the design and architecture of the simulation model. The design of each sensor node is configured to detect underwater pollution. The efficiency of the system is more stable and manageable than the monitoring process involving existing human surveillance by testing with the simulation model. The underwater sensor network we design provides a suitable hardware platform for future work on the medium access control protocol.

Main contributions of this research are as follows: (i) priority classes, namely, oxidation-reduction potential, pH, conductivity, flow are taken into consideration to acquire the most important sensor data packets primarily, (ii) Aloha based medium access technique is employed for underwater sensor nodes, (iii) throughput performance, and average delay are evaluated, (iv) analytical results obtained from Matlab software are validated with the simulation results obtained from Riverbed software, and (v) to the best of authors knowledge, Aloha based smart system for pollution control in underwater wireless sensor networks is designed and simulated in Riverbed software for the first time in the literature.

2. A SMART SYSTEM FOR WATER POLLUTION CONTROL

In this study, a cost-effective medium access protocol for pollution control in underwater wireless sensor networks was designed and simulated. After the foundation and design of the proposed network structure were completed, it was simulated with Riverbed Modeler software. To determine whether a particular region in the seas or oceans is clean in terms of eatable fishing, it is thought that the chemical properties of the water in the sea can be monitored for a long time with the help of sensor nodes.

Riverbed Modeler software provides design, simulation and data collection properties. Riverbed Modeler also supports a comprehensive development environment that includes the modeling of wireless networks and distributed network systems. In Riverbed software, performance evaluation of a simulation model is evaluated by discrete event simulations. The source code of Riverbed Modeler is written in Proto C programming language.

2.1 Underwater Sensor Network Design and Simulation

The underwater sensor network design shown in Figure 1 has a large number of sensors located underwater. The sensors communicate in an ad-hoc manner employing the Aloha-based technique. The advantages of the Aloha technique over other access techniques are as follows: (i) Simple. (ii) No synchronization among users is required. (iii) Performs high throughput under light load conditions. (iv) The probability of collision decreases as the number of users decreases. (v) Adaptable to a changing station population. (vi) Transmission may start anytime.

When necessary, they transmit their data to each other and transfer their data to the surface node. They use the Aloha-based technique, which is a cost-effective protocol as a medium access technique. There is also a surface node used to collect data from underwater sensor nodes. The task of the surface node is to transfer data from the sensor nodes to the coast station. The data collected by the coast station is monitored from any online

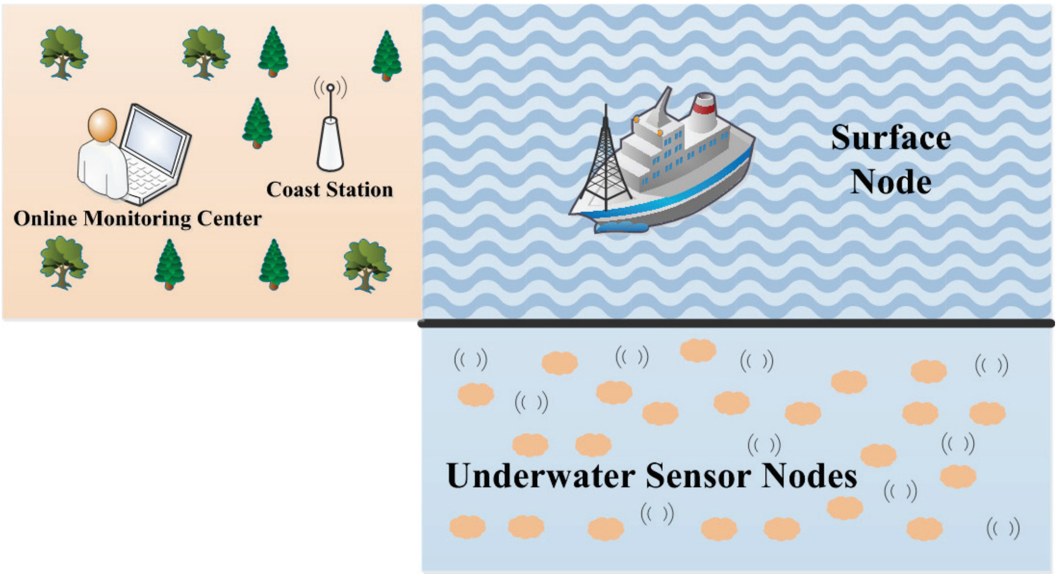

Figure 1 Underwater sensor network design

Table 1 Underwater sensor network simulation parameters.

Parameter	Value
Data rate	10 Kbps
Packet size	50 byte
Delay	25 us
Frequency	25 Khz
Simulation time	3600 sn
Sending power	2 mW
Receiving power	0,75 mW
Number of sensor	22

monitoring center in the vicinity or any remote smart device. The surface node is also a coordinating node that directs the data traffic of the underwater sensor nodes.

Table 1 shows the sensor network parameters used in the simulation model. The data rate is about 10 Kbps due to the nature of high density based underwater networks. For pollution control in underwater sensor networks, sensors such as pH, flow, conductivity and oxidation-reduction potential should be utilized.

A pH meter is used to determine the acidity or alkalinity of the solution [23]. pH is the concentration of hydrogen ions in the solution. When the probe is placed in a solution to measure the pH, hydrogen ions accumulate around the bulb and replace the metal ions from the bulb. The voltage of this electric flow is measured by the pH meter by converting it into pH value. An increase in acidity of the solution has a greater concentration of hydrogen ions that increases the voltage [24]. This increased voltage decreases the pH reading in the pH meter.

There are many different technologies used in the measurement of flow [23]. The choice of the most suitable type relies on a wide range of factors including the nature and viscosity of the fluid Differential pressure flow meters insert an obstruction in the flow stream to reduce the flow rate [25]. The flow rate is calculated by taking the difference between upstream and downstream pressures.

Measuring electrical conductivity in liquid substances is a highly powerful diagnostic and analytical tool in a range of applications An electrolyte is a liquid that contains ions. Hence the liquid quality can be assessed by determining the conductivity [24]. The liquid conductivity is based on two temperature-dependent parameters that include ion concentration and their mobility.

Oxidation-reduction potential measures the ability of a sea or ocean to cleanse itself or break down waste products, such as contaminants and dead plants and animals [23]. When the value is high, there is a lot of oxygen present in the water [25]. In general, the higher the oxidation-reduction potential value, the healthier the sea or ocean is. However, even in healthy seas and oceans, there is less oxygen when getting closer to the bottom sediments [26].

2.2 Aloha Based Medium Access Technique

In the Slotted Aloha technique, the time α is divided into pieces equal to the length of the slots, equal to or greater than the duration of the packet [27, 28, 29]. Each sensor node can only send packets at the beginning of the time slot [30, 31, 32]. If there is a ready packet out of the beginning of the period of a node, it waits until the beginning of the next time slot [33, 34, 35].

In Figure 2; Packet 1, Packet 2, and Packet 3 are sent without collision, while Packet 4 and Packet 5 collide with each other. Therefore, these two packages need to be sent again in the next periods. In the Slotted Aloha technique, the time that the nodes

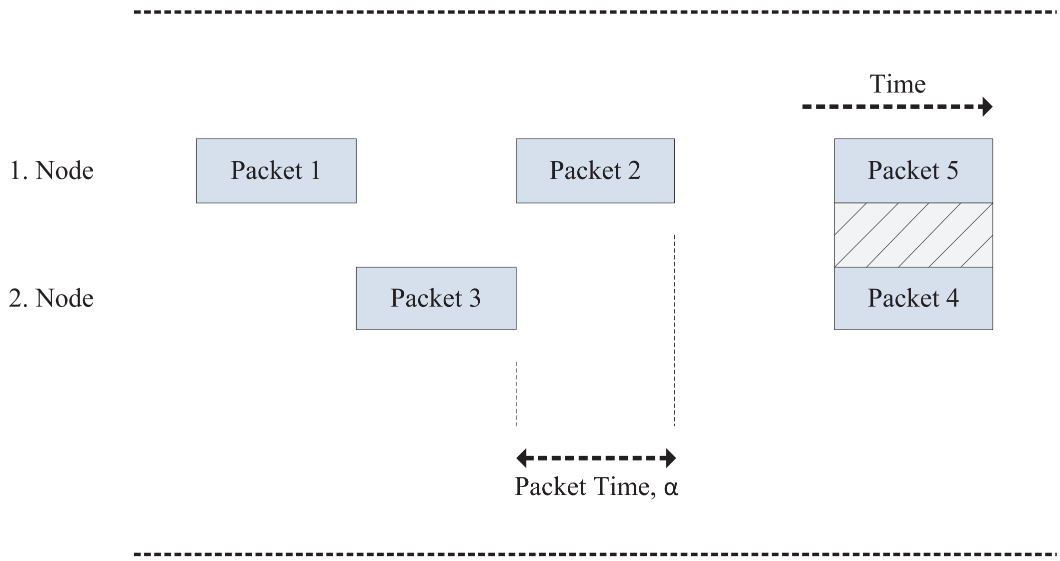

Figure 2 Slotted Aloha technique sample packet transmission

wait before sending again determines the delay characteristics of the traffic. The critical time for Slotted Aloha is just a packet time because partial collisions do not occur. The possibility of no further submissions during the critical period is as below;

$$e^{-G} \tag{1}$$

where G is the average load. Throughput performance rate, S, is as follows;

$$S = G * e^{-G} \tag{2}$$

where the performance rate of the Slotted Aloha protocol is obtained. The performance rate is obtained when the maximum load is 1 and it is around 0.36. The delay expression of the Slotted Aloha technique D is given below;

$$D = t_p + (e^G - 1) \tag{3}$$

where t_p is the propagation delay. The average delay is about 0.16 ms for the proposed underwater sensor network.

The positive aspects of the Slotted Aloha technique for underwater sensor networks are as follows: (i) Partial collisions are prevented as packet transmission is not initiated outside of time slots. (ii) In cases where a lot of packet transmission is carried out, it is more efficient than the systems operating according to the fixed allocation principle. (iii) Since it has a feedback system, it is ensured that the packets are transmitted successfully. (iv) It is easy to add and remove new node sensors to the underwater sensor network.

2.3 Priority Classes Among Underwater Sensor Nodes

In this study, a non-preemptive priority model of the sensor node process for underwater wireless sensor networks is proposed. In the proposed system model, priority-based data traffic is employed to meet the requirements of the sensor nodes. Packets of sensor nodes are grouped into four different priority classes, i.e.; pH, flow, conductivity, and oxidation-reduction potential. Because throughput performance and average delay are the most important parameters for underwater sensor networks, the analytical model and simulation model are evaluated using these parameters.

Oxidation-reduction potential data packets have the highest priority; pH data packets have the second-highest priority, conductivity data packets have the third-highest priority, while flow data packets have the lowest priority. In the non-preemptive priority model, the next packet waits until the continuing transmission is over even if the next packet has a higher priority than the present packet. Taking priority classes into account, the throughput performance of the proposed system is defined as below where P_C denotes priority classes:

$$S = G * e^{-G} * P_C \tag{4}$$

P_C value changes according to the priority class of the sensor node. To calculate throughput performance for the highest priority class, oxidation-reduction potential, the following equation is defined:

$$S = G * e^{-G} * (P_C - 0.05) \tag{5}$$

To calculate throughput performance for the second-highest priority class, pH, the following equation is defined:

$$S = G * e^{-G} * (P_C - 0.1) \tag{6}$$

To calculate throughput performance for the third-highest priority class, conductivity, the following equation is defined:

$$S = G * e^{-G} * (P_C - 0.15) \tag{7}$$

To calculate throughput performance for the lowest priority class, flow, the following equation is defined:

$$S = G * e^{-G} * (P_C - 0.2) \tag{8}$$

According to the waiting time of sensor nodes with priority classes, the average delay is expressed as below where P_d denotes priority delay:

$$D = [t_p + (e^G - 1)] * P_d \tag{9}$$

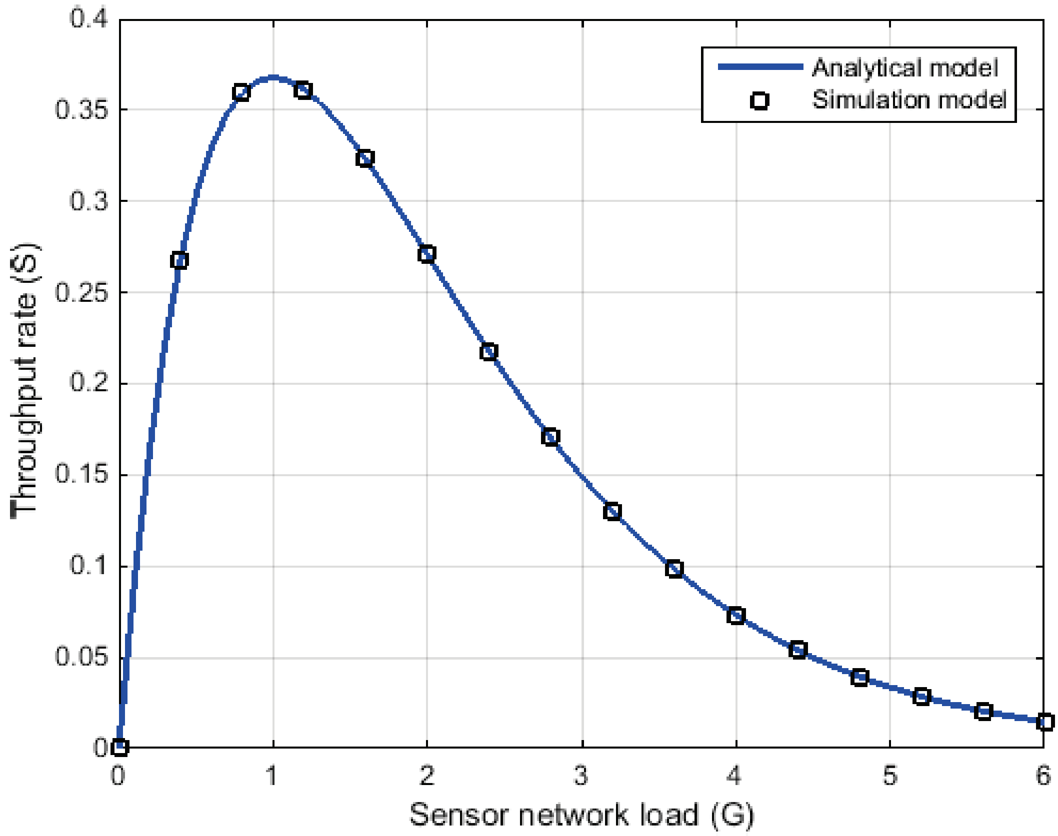

Figure 3 Slotted Aloha technique throughput rate

P_d parameter varies among 0.01 to 0.04 considering priority classes of different sensor nodes, i.e., 0.01 for highest priority class, 0.02 for the second-highest priority class, 0.03 for the third-highest priority class, and 0.04 for the lowest priority class.

3. GRAPHICAL RESULTS

In this section, analytical and simulation of the proposed underwater sensor network are analyzed with comparative graphical results. Analytical results obtained from Matlab software are validated with the simulation results obtained from Riverbed software [36, 37].

Figure 3 shows a graphical result of the performance ratio of the Slotted Aloha technique according to the sensor network load.

When the graphical result in Figure 3 is examined, it is seen that the sensor network load varies between 0 and 6. The highest performance ratio is 0.36 is acquired when the network load is 1. Besides, the results of the mathematical model overlap with the results of the simulation model.

Figure 4 shows a graphical result of the delay analysis of the Slotted Aloha technique. When the graphical result is examined, it is seen that the delay value varies between 0.14 and 0.16 during the simulation period. The lowest latency is 0.15 in the middle of the simulation time. Also, the results of the simulation model overlap with the analytical model results.

Figure 3 and Figure 4 show the validity of the proposed underwater sensor network-based cost and delay efficient medium access technique owing to the condition that the simulation model and analytical model results are very close. The findings clearly show that the cost-effective underwater sensor network model we developed the simulation model can be used in real underwater environments such as the sea, lake, etc. as it provides the targeted features.

In Figure 5, a graphical result of the throughput performance for high priority classes is shown. When the graphical result is examined, it is seen that the maximum throughput of the oxidation-reduction potential sensor node is about 0.35 when the sensor network load is 1. The throughput for the pH sensor is about 0.33 when the network load is 1. Besides, it is seen that the results of the analytical model overlap with the simulation model results.

In Figure 6, a graphical result of the throughput performance for low priority classes is shown. When the graphical result is examined, it is seen that the maximum throughput of the conductivity sensor node is about 0.32 when the sensor network load is 1. The throughput for the flow sensor is about 0.29 when the network load is 1. In addition, it is clearly seen that the results of the analytical model overlap with the simulation model results.

In Figure 7, a graphical result of the throughput performance for high priority classes is shown for the double data rate. When the graphical result is examined, it is seen that the maximum throughput of the oxidation-reduction potential sensor node is about 0.39 when the data rate is doubled. The throughput for the pH sensor is about 0.37 when the network load is 1 with the help of a double data rate. In addition, it is clearly seen that the results of the analytical model overlap with the simulation model results.

In Figure 8, a graphical result of the throughput performance for low priority classes is shown with the double data rate. When

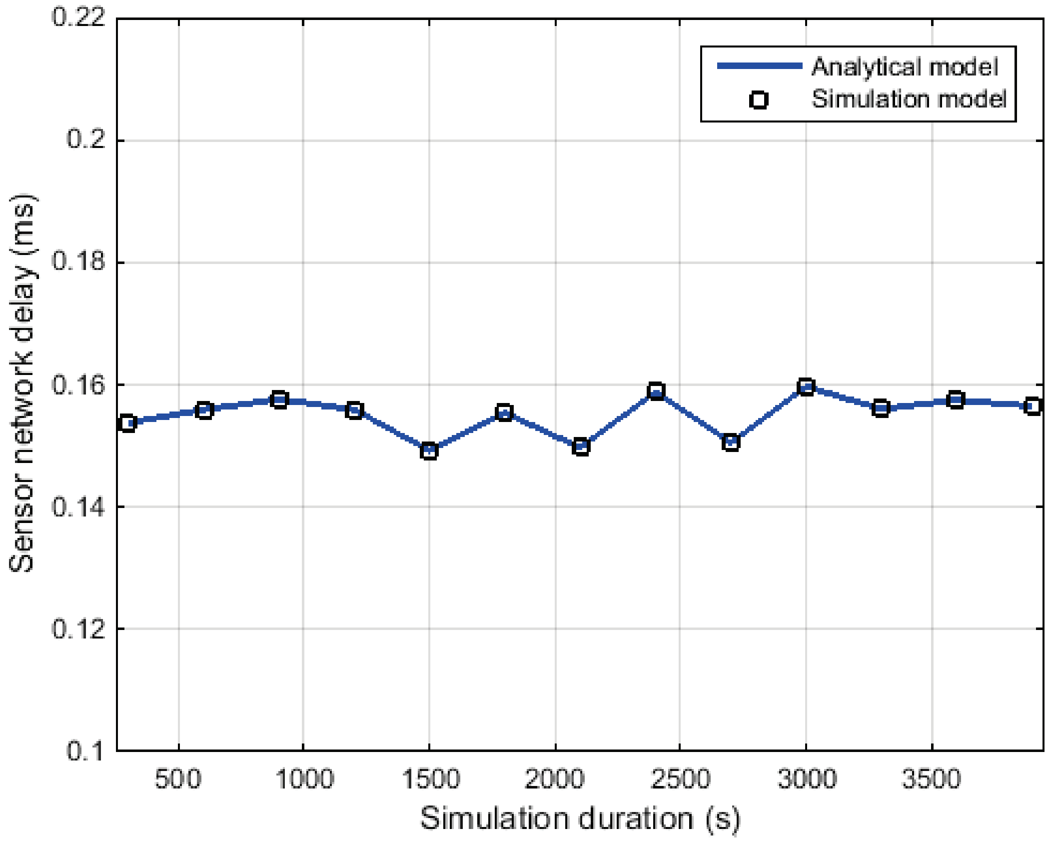

Figure 4 Slotted Aloha technique delay analysis

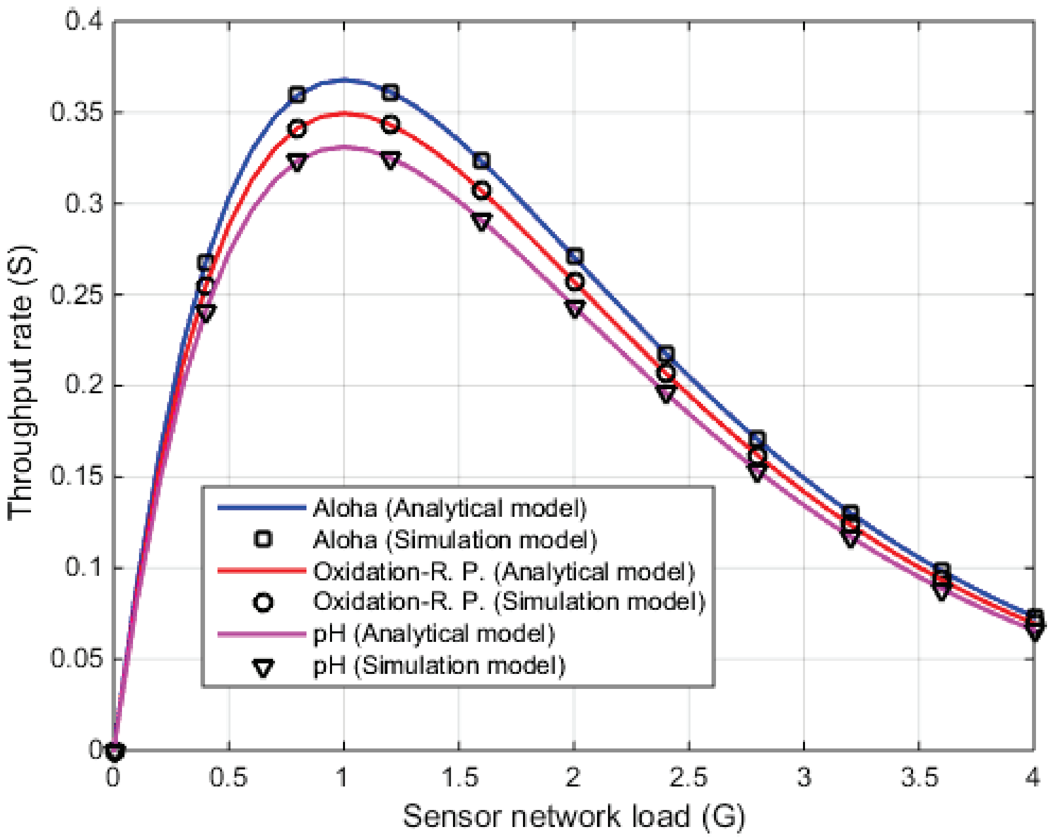

Figure 5 Throughput for high priority classes

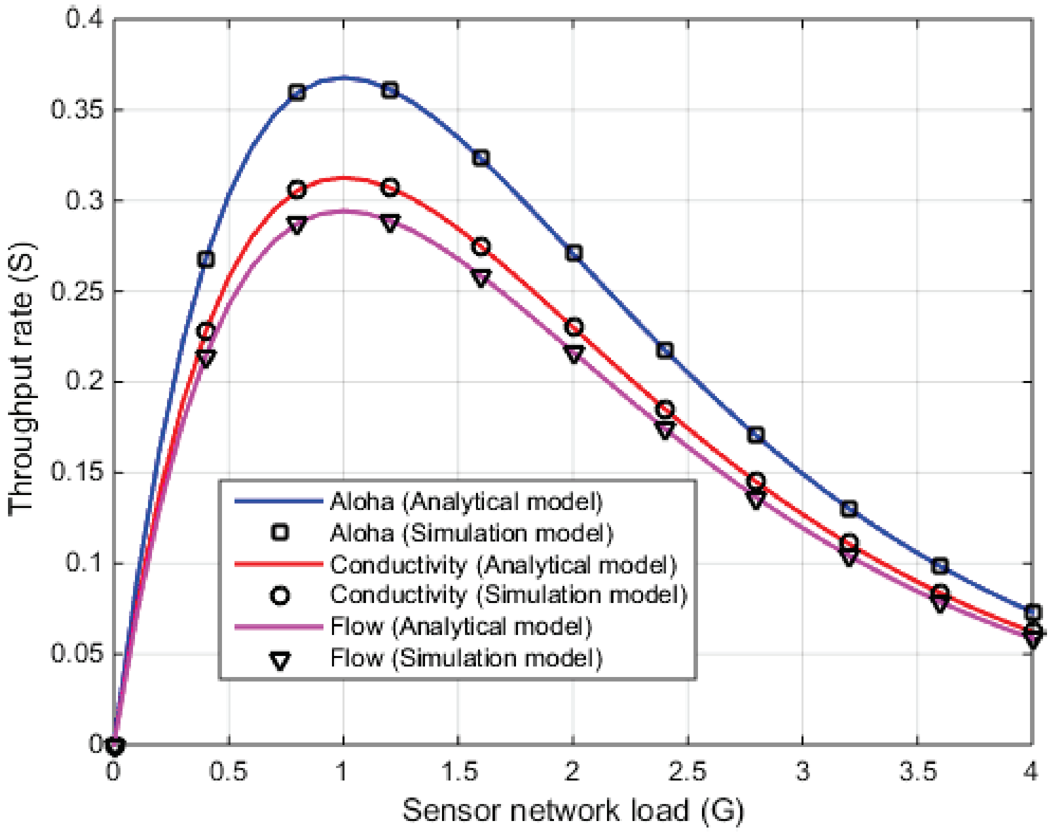

Figure 6 Throughput for low priority classes

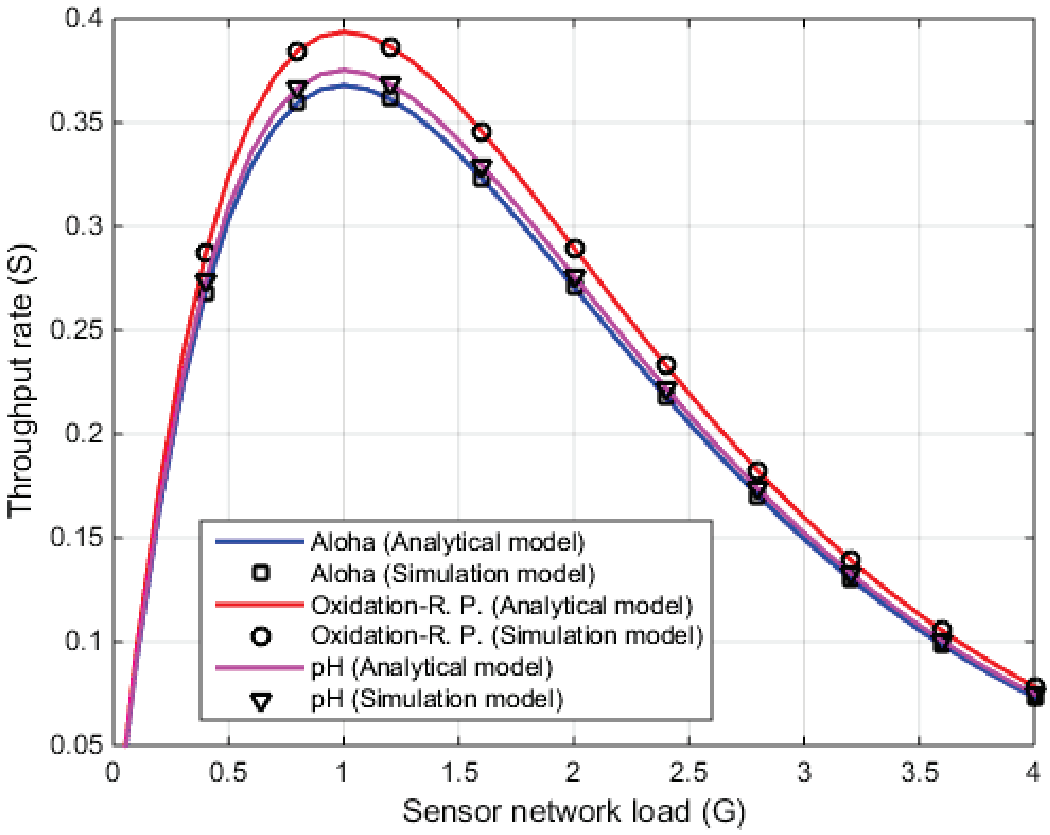

Figure 7 Throughput for high priority classes with double data rate

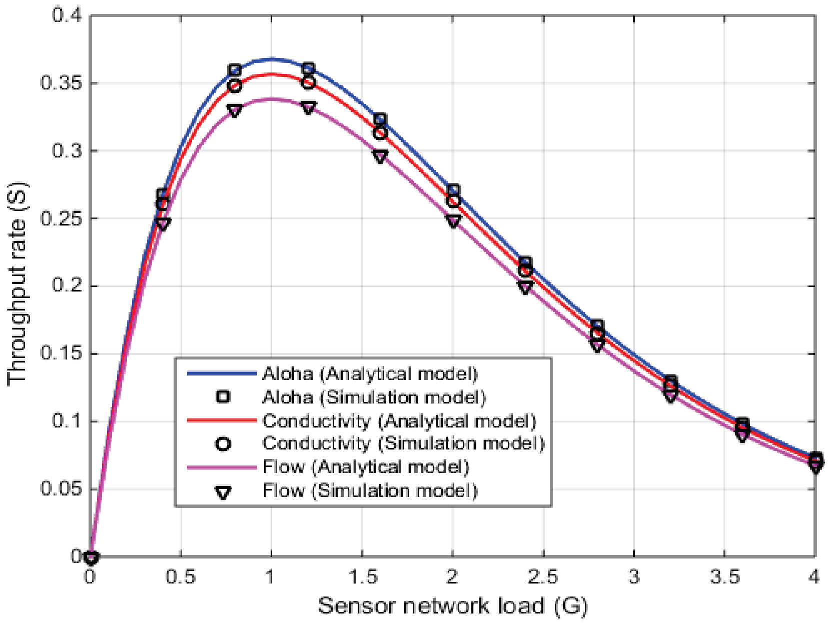

Figure 8 Throughput for low priority classes with double data rate

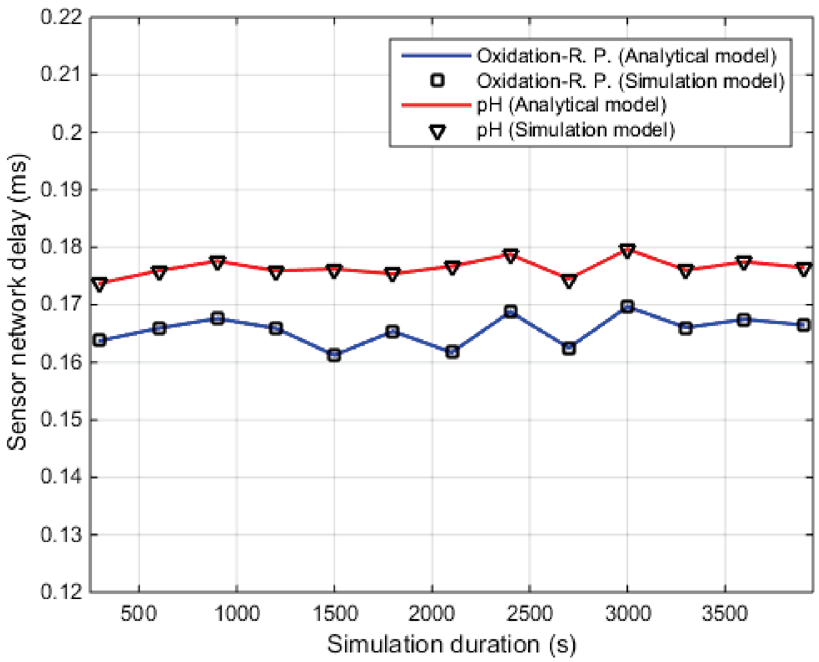

Figure 9 Delay analysis for high priority classes

the graphical result is examined, it is seen that the maximum throughput of the conductivity sensor node is about 0.36 when the data rate is doubled. The throughput for flow sensor is about 0.34 when network load is 1 with the help of a double data rate. In addition, it is clearly seen that the results of the analytical model overlap with the simulation model results.

Figure 9 shows a graphical result of the delay analysis of the high priority classes. When the graphical result is examined, it is seen that the delay value varies between 0.16 and 0.17 for the oxidation-reduction potential sensor during the simulation period. The delay value varies between 0.17 and 0.18 for pH sensors during the simulation period. In addition, it is clear that the results of the simulation model overlap with the analytical model results.

Figure 10 shows a graphical result of the delay analysis of the low priority classes. When the graphical result is examined, it is seen that the delay value varies between 0.19 and 0.2 for the flow sensor during the simulation period. The delay value varies between 0.18 and 0.19 for the conductivity sensor during the simulation period. In addition, it is clear that the results of the simulation model overlap with the analytical model results.

4. CONCLUSION AND FUTURE WORK

The proposed simulation model defines the intelligent sensor-based monitoring system that identifies and alarms the formation of underwater pollution. Aloha was chosen as the medium access

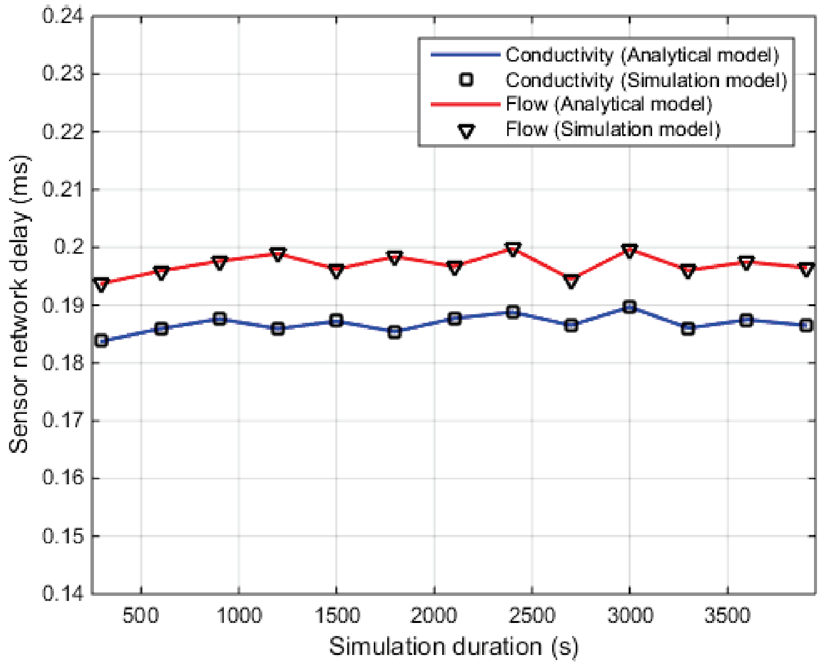

Figure 10 Delay analysis for low priority classes

protocol in order to be cost-effective in the system we designed the simulation model. The efficiency of the system has been shown to be more stable and manageable than the monitoring process involving existing human surveillance by testing with the simulation model.

In future studies, this work can be carried out to solve different problems related to the monitoring system in underwater networks. Since underwater pollution monitoring and pollution control systems are not used in today's world as application, the designed systems can be tested on the simulation models and the results can be observed.

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