Personal and Ubiquitous Computing
https://doi.org/10.1007/s00779-018-1136-3

ORIGINAL ARTICLE

Node scheduling problem in underwater acoustic sensor network using genetic algorithm

V. Sivakumar[1,2] · D. Rekha[1]

Received: 19 February 2018 / Accepted: 26 March 2018

Abstract

Underwater acoustic sensor network (UWASN) has recently aroused the interest of researchers and scientists in this field. The acoustic sensor bandwidth is limited in underwater and it causes low successful packet transmission. One of the methods to overcome this handicap is efficient broadcast scheduling of underwater acoustic sensor node (UASN) that would help in transmitting and receiving data without any collision. This can be done with the help of time division multiple access (TDMA). The basic idea is to address broadcast scheduling problem in UWASN for utilizing the limited available bandwidth by parallelizing the node transmission such that it does not interfere with each other in same time slot; it also minimizes the node turnaround transmission time in the network by optimizing the time slots in TDMA frame. The objective of this paper is to maximize the utilization of the available underwater acoustic bandwidth and to achieve high throughput as well as to reduce the node turnaround wait time by using an evolutionary genetic algorithm (GA). The simulation results prove that every node in the UWASN transmits in an average minimal turnaround time by minimizing the time slots and maximizing the throughput in the network by scheduling the possible nodes with parallel transmission.

Keywords Underwater acoustic sensor network · Broadcast node scheduling · Time division multiple access · Genetic algorithm

1 Introduction

Underwater acoustic sensor network (UWASN) is a special kind of ad hoc network which plays a significant role in research works due to large emerging applications in underwater. Because of the frequent changes in weather conditions, natural disasters such as tsunamis, storms, and hurricanes take place in many parts of the world. Such type of disasters affects the people in coastal areas and causes a lot of damage to their lives. The traditional approach for disaster monitoring is to deploy an underwater sensor and collect the data manually [1]. This traditional approach drawback of non-delivery of timely information created great interest in the idea of underwater sensor network. To handle these disasters by using underwater sensor network, there is need for efficient communication medium to share the data. At first, electromagnetic waves are successfully used for short distance communication, but it is not sufficient enough for long distance transmissions because of the high attenuation in underwater [2], whereas the optical waves get quickly absorbed and scattered in the water, which in turn can be used for very short distance communication [3]. The acoustic waves overcome the above drawbacks and can communicate over long distances with less absorption and attenuation at low frequency [4]. Since acoustic wave propagates as a pressure wave, it can send its frequency over many kilometers to cover longer distances. But the acoustic signal has its own disadvantages like limited bandwidth [BW] and long propagation delay because of the low speed of the audio signal in underwater (approximately 1500 m/s) [5].

Today's underwater acoustic sensor networks are of single and multi-hop networks, which rely on hardware-based infrastructure. To overcome the dependency on this hardware infrastructure, a new next-generation underwater software-defined networks called SoftWater has been introduced in [6]. Regarding the network connectivity in underwater communication, each sensor node forwards data dynamically. In the single-hop underwater acoustic network, each node can communicate directly with all other nodes in its connectivity [7]. In the multi-hop underwater acoustic network, all intermediate

✉ V. Sivakumar
sivakumarvit2013@gmail.com

1 School of Computing Science and Engineering, VIT, Chennai Campus, Chennai 600127, India

2 Department of Software Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai 603203, India

Published online: 24 April 2018

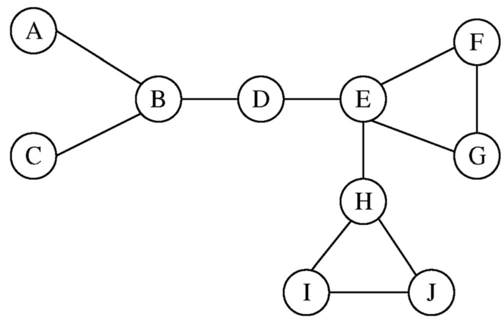

Fig. 1 A simple ten-node underwater acoustic multi-hop sensor network

$$(\mathrm{HOP\_MAT}) = \begin{array}{cc} & \begin{matrix} A & B & C & D & E & F & G & H & I & J \end{matrix} \\ \begin{matrix} A \\ B \\ C \\ D \\ E \\ F \\ G \\ H \\ I \\ J \end{matrix} & \begin{pmatrix} 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 0 \end{pmatrix} \end{array}$$

Fig. 3 Ten-node two-hop connectivity matrix

nodes collect and forward the data packets via an acoustic link. Because of the special features of underwater channel, terrestrial wireless network protocols cannot be applied directly in the underwater wireless network [8]. UWASN constitute some exclusive challenges in the medium access control (MAC) protocol with contrast to terrestrial networks. One of such major challenges is limited available bandwidth that results in large propagation delay that has been significantly affecting the packet transmission duration [9]. Depending on the kind of application, there may be some other parameters like temperature, salinity, and pressure that need to be considered which also influence the transmission in underwater.

The major function of MAC protocols is to provide reliable and efficient access to the shared physical medium which directly influences the throughput, delay, energy consumption, and the error rate in the network. The most popular MAC protocols are ALOHA and Slotted ALOHA for low packet rate transfer [10] and handshake-based protocol for collision avoidance [11] which does not work well because of the underwater (UW) characteristics. Because of the narrow bandwidth of the underwater acoustic channel, frequency-division multiple access (FDMA) does not work well in UW [12]. Time-division multiple access (TDMA) distributes distinctive scheduled slot for transmission that in turn produces excessive throughput even for massive traffic networks as compared to the abovesaid protocols. In underwater, it is proven that TDMA works well for an extended period of time interval and avoids collision efficiently [13]. TDMA protocol can also be used to resolve the exact constraints of underwater acoustic communication [14]. In conventional TDMA, a number of nodes involved in the network have their own time slots for their transmission. This has a drawback of very long schedule for getting a chance for subsequent node transmission. Recently, many TDMA-based MAC protocols for underwater have been introduced [13, 15, 16], which have major problems of broadcast scheduling. Hybrid spatial reuse TDMA (HSR-TDMA) [17] for broadcast scheduling uses graph coloring algorithm to increase the underwater channel utilization in the multi-hop network, but the problem of hidden and exposed terminal has not been addressed properly. In HSR-TDMA, there is a disadvantage that few nodes in the network suffer from very long turnaround time for their subsequent transmissions that in turn affects the overall UWASN throughput. This broadcast node scheduling problem can be resolved by using evolutionary algorithm which works successfully for any optimization problem [18, 19]. In this paper, anchored or fixed underwater acoustic sensor nodes (UASNs) are been considered for broadcast scheduling problem for the applications that require frequent and periodic transmission, and it is solved with genetic algorithm.

The main purpose of this article is to provide average minimum turnaround node transmission wait time and to increase the utilization of underwater acoustic bandwidth. The remaining segment of this paper is arranged as follows. Section 2 explores underwater broadcast node scheduling conflicts. Section 3 investigates the problem formation for UW broadcast node scheduling. Section 4 describes the genetic algorithm and its operations for solving the underwater broadcast

$$(\mathrm{CON\_MAT}) = \begin{array}{cc} & \begin{matrix} A & B & C & D & E & F & G & H & I & J \end{matrix} \\ \begin{matrix} A \\ B \\ C \\ D \\ E \\ F \\ G \\ H \\ I \\ J \end{matrix} & \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \end{pmatrix} \end{array}$$

Fig. 2 Ten-node connectivity matrix

$$(\mathrm{TDMA\_MAT}) = \begin{array}{cc} & \begin{matrix} A & B & C & D & E & F & G & H & I & J \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \end{matrix} & \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \end{array}$$

Fig. 4 Traditional TDMA frame with ten time slots and ten joining node

$$(\text{TDMA\_MAT}) = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \begin{array}{c} \begin{array}{cccccccccc} A & B & C & D & E & F & G & H & I & J \end{array} \\ \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \end{array}$$

Fig. 5 Optimal GA-TDMA frame

scheduling problem. Section 5 reports the experimental simulation results of underwater scheduling, and Section 6 draws the conclusion.

2 Underwater broadcast node scheduling conflicts

In multi-hop static UWASN, the major packet collision in broadcasting is due to two reasons. First, if the adjacent node in the network starts transmitting simultaneously, it will end up with primary collision. Second, if two or more node packets approach a single node in the same time slot, it may end up with the secondary collision. The secondary collision happens due to the concurrent transmission of two-hop away nodes from the sender node. These primary and secondary conflicts are dealt with hidden and exposed terminal problems. This problem is avoided by allowing two or more nodes to transmit in the same time slot without any conflict, if the nodes are located with an extended gap of two hops away. Other than primary and secondary conflicts, the most ambitious issue of the underwater scheduling problem is non-trifling propagation delay. The reasons are continuous change in water temperature, salinity, pressure, and other complications. But this can be avoided by adding guard time and size of maximum accepted propagation delay in the underwater channel plus a packet with maximum transmission length.

In TDMA-based MAC protocol for underwater acoustic communication, guard time is added after every sending time of a packet to avoid collision [20]. This guard time prevents the early reception and delayed reception of the packet in the same time slot [21]. The greater size of expected propagation delay in the underwater channel can be reduced by using propagation estimation to stagger transmissions [22]. Underwater scheduling is limited by half-duplex communication wherein one node can send or receive but cannot do both functions at the same time [4]. In HSR-TDMA, both conflicts have been overcome and increased the number of transmissions with the drawback of utilizing the maximum node time slots involved in the network [17]. The HSR-TDMA also suffers from long turnaround wait time for the few node transmissions in the network that causes least successful packet transmission rate (STR) [17]. As a result, if the number of nodes in the UWASN increases, those few nodes have to wait for a very long time for their subsequent transmissions that directly affects the overall network throughput. Therefore, the primary intention of this work is to develop an underwater TDMA broadcast scheduling with an average minimal turnaround wait time for the node subsequent transmission by minimizing the time slots in TDMA frame and achieving maximum utilization of acoustic sensor node bandwidth by scheduling the possible parallel nodes for its transmissions in the TDMA frame.

Table 1 Simulation parameter

Parameters	Values
Population size	40
Crossover rate	0.32
Mutation rate	0.01
Max. generation	500

3 Problem formations for underwater broadcast node scheduling

UWASN can be represented by an undirected network U(Y, E), where Y accounts for the number of UASN involved in the network and E stands for set of the bidirectional link between nodes [23]. A link E(i, j) conveys that node i and j are connected within acoustic transmission range. Figure 1 represents a simple underwater acoustic multi-hop sensor network referred from [17]. Each node is connected to the neighbor node to form a link between them.

Here Y = A, B, C, D, E, F, G, H, I, J and |Y | represent the number of nodes in the given network. As mentioned in Section 2, to avoid broadcast conflict, the primary and secondary collision should be dismissed. The primary collision is avoided by identifying the connectivity matrix of the network, and the secondary collision is avoided by recognizing of two-hop connectivity of the network. Both these matrices are used for the reference to avoid collisions in the same time slot and also to increase the possible parallel node transmissions. The identified connectivity matrix (CON_MAT) for the given underwater network is given in Fig. 2.

Each row in (CON_MAT) accounts for a direct relationship between the nodes. And each column in (CON_MAT) represents underwater acoustic sensor nodes involved in the network. The matrix contains 0 and 1 s where all 1 s represent link existence. Two-hop connectivity for the given UWASN is recognized as hop matrix (HOP_MAT) shown in Fig. 3. Here, the row value tells one- or two-hop connection between nodes, and column represents underwater acoustic sensor nodes in the network. The value contains 0 or 1 s where all “1 s” show that it might be one or two hops apart from the selected node.

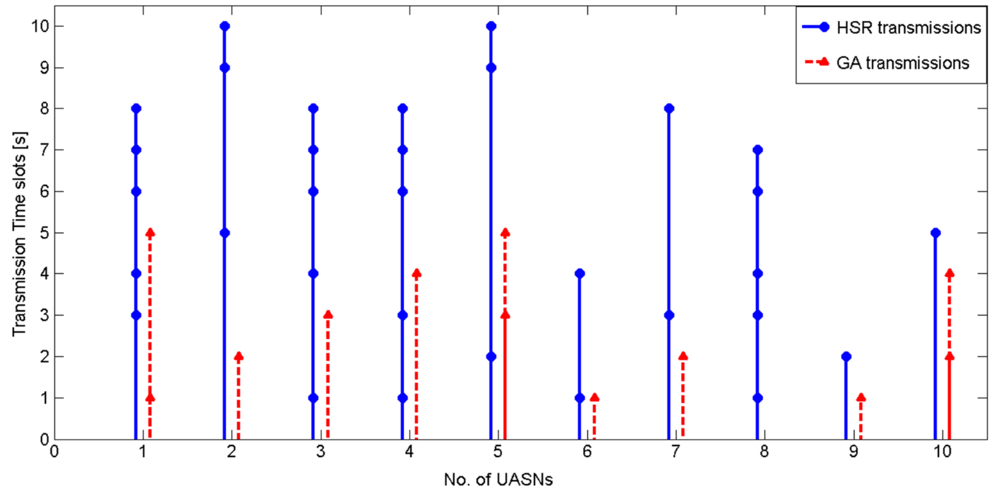

Fig. 6 Comparison between HSR and GA TDMA frame for ten-node UWASN

The scheduler matrix (TDMA_MAT) is a X × Y matrix where X is the number of time slots and Y = {y1,y2...yn} is the total number of UASNs in the network which is shown in Figs. 4 and 5. Here, row represents a number of time slots and column represents the joining nodes (transmitting nodes) in the network. It takes values 0 and 1 s where all 1 s represent joining nodes to transmit in that particular time slot without any interference. Figure 4 represents one probable traditional TDMA frame for the given UWASN. Figure 5 accounts for an optimal GA-TDMA frame with minimal time slot and maximum possible parallel node transmission for the given network. Here in first-time slot, the joining nodes are A, F, and I without any interference.

Since underwater scheduling has proven to be non-deterministic polynomial (NP) complete in [15], as a result, there is no efficient problem-solving approach to solve the problem. Genetic algorithm [GA] is one such technique that solves the NP complete problem with an optimal solution. For this broadcast node scheduling problem, the tight lower bound is introduced to find whether the GA has achieved the optimal solution.

Tight lower bound is determined by

$$HD = \max_{y \in Y} |Ds(y)| \tag{1}$$

Let Ds (y) be set of degrees of y nodes, and HD represents the highest degree of node connectivity in UWASN.

Table 2 Comparison of GA-TDMA and HSR-TDMA frame length

No. of UASNs	No. of links	GA-TDMA frame length	HSR-TDMA frame length
10	22	5	10
25	43	7	25
50	98	9	50
100	200	10	100

Based upon this highest degree of node connectivity in the network, the tight lower bound value is generated as

$$\Delta = |X| - HD \geq 1 \tag{2}$$

If solution Δ = 1, then it has reached the optimum. This optimum shows the minimization of time frame length with at least one transmission for every node in the network.

4 Genetic algorithm

The basic motivation of the genetic algorithm is survival of the fittest. Genetic algorithm (GA) is a particular class of evolutionary algorithms that uses techniques inspired by biological evolution such as inheritance, mutation, selection, and crossover. GA is a heuristic search algorithm based on the natural selection mechanism used in computing to find the actual or nearby result of optimization [24]. The genetic algorithm is applied as a computer simulation in which a population of abstract representations (called chromosomes or the genotype or the genomes) of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem which evolve towards better solutions [24]. The idea of evolution starts from the possible set of solutions that is the population of randomly generated individuals. Two parents are selected according to their fitness out of the population. It iterates that through all generations and in every generation, the best child is selected for the propagation of next generation by evaluating the fitness function. The algorithm generally stops either on reaching the maximum generation or by satisfying the fitness level of some specified stopping criteria. GA is robust in the search process for NP-complete problems [25].

In general, GA takes the different permutations of traditional TDMA matrices, where each node transmits in a separate time slot. This traditional TDMA matrix forms the initial population for this problem. By selecting two parents, from the

Table 3 Simulation results for genetic algorithm TDMA

No. of UASNs	No. of links	Avg. ND	Max ND	Optimal TDMA frame length	Avg. UW acoustic BW utilization α	Avg. no. of generations	Computation Time
10	22	4	4	5	0.245	32.2	0.7 s
25	43	5.2	6	7	0.166	41.6	1.17 min
40	67	5.7	6	7	0.167	51.1	1.91 min
50	98	6	8	9	0.128	56	2.45 min
65	110	6.3	8	9	0.128	68	5.18 min
75	155	7.2	9	10	0.116	80	7.25 min
100	200	7.6	9	10	0.11	102.2	13.03 min

initial population GA starts the iteration process to evolve population. The algorithm stops either by reaching the optimal solution by satisfying the tight lower bound $\Delta = 1$ or on satisfying the maximum run of the algorithm (500 iterations). Algorithm 1 provides the overview of GA and in each step of the iteration, it performs following steps.

Algorithm 1: Genetic algorithm

```
Initialization
Generate possible solutions randomly (Gpop);
Evaluate
evaluate (Gpop);
GA Operations
while condition not terminated do
    Gs = select(Gpop);
    Gc = crossover(Gs);
    Gm = mutation(Gc
    Gnew = evaluate(Gm);
    Gpop = survival(Gpop,Gnew);
end
```

4.1 Selection operators for underwater scheduling

The iterations are operated with the selection, crossover, and mutation operators. The natural selection operator selects a half percentage of chromosomes from the population for reproduction. Initially, all TDMA frames have the same fitness that is calculated by the Eq. (3). These different TDMA frame matrices are gathered in a mating pool. From the mating pool, GA selects two parents based on their fitness to produce the next generation. This selection is made consciously with the probability of producing good parents for the next generation. In each generation, the child is checked for primary and secondary conflicts using (HOP_MAT) to avoid collisions. If it violates, then, the child is penalized by not going to the next generation. If it is satisfied, its fitness is evaluated for the propagation of next generation.

4.2 Crossover operator

While comparing with other optimization techniques, crossover plays an important role in GA. The selection operator selects two individuals from the population. The crossover operator selects random bit strings in the individuals for

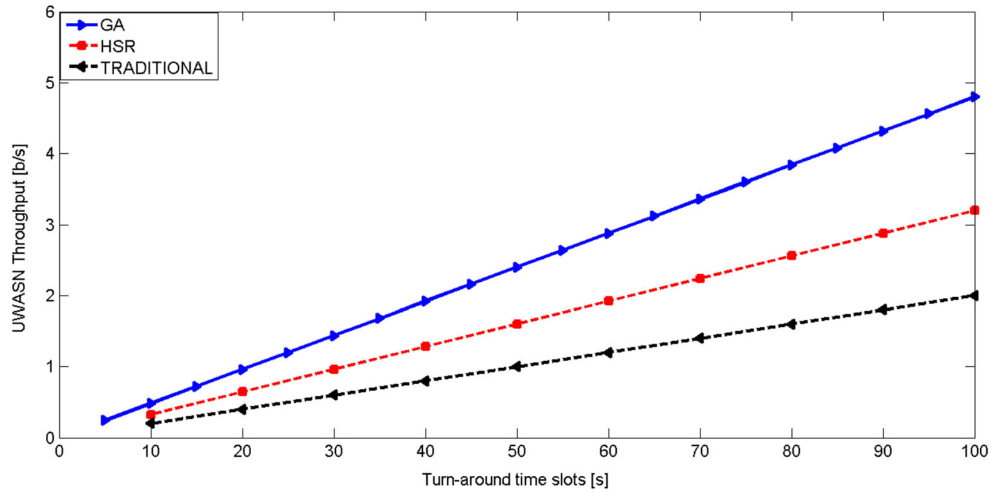

Fig. 7 Comparison of ten-node UWASN throughput

exchanging information between them. Bit strings are interchanged up to the specified crossover point.

For example, consider two parents P 1 = 0000 and P 2 = 1111 with random crossover point as two, the C1 = 1100 and C2 = 0011 is the offspring produced after crossover. Exactly in every iteration fitness is evaluted for offspring for better solution. If the offspring is fitter, then, it replaces its parent in the population for the next generation. By combining the good individuals, the next generation will obtain optimal individuals.

4.3 Mutation operator

A mutation in GA maintains the condition within the population and prevents premature convergence. In this problem after crossover, some bits are flipped based upon the non-violating conflict condition. This mutation is done by flipping 0 to 1 s by referring the (HOP_MAT) to avoid conflicts. Then fitness of the solution is evaluated again to overcome the deficiency in previous generation fitness. The child with higher fitness is selected for next iteration.

4.4 Fitness evaluation of chromosomes

The fitness function is defined based on the measurement of each population. In this problem, the fitness function depends on the following criteria: (1) underwater acoustic bandwidth utilization to find the development in high successful packet transmission which is evaluated by Eq. (3); (2) tight lower bound $\Delta = 1$ given in Eqs. (1) and (2) for stopping the GA. The terminal condition determines whether the solution has reached the optimal solution or is forcing to stop the algorithm; (3) average time delay in underwater network is measured by Eq. (4).

Underwater acoustic bandwidth utilization for entire UWASN

$$\alpha = \frac{1}{X.Y}\left[\sum_{i=1}^{X}\sum_{j=1}^{Y}\left(\mathrm{TDMA\_MAT_{ij}}\right)\right] \tag{3}$$

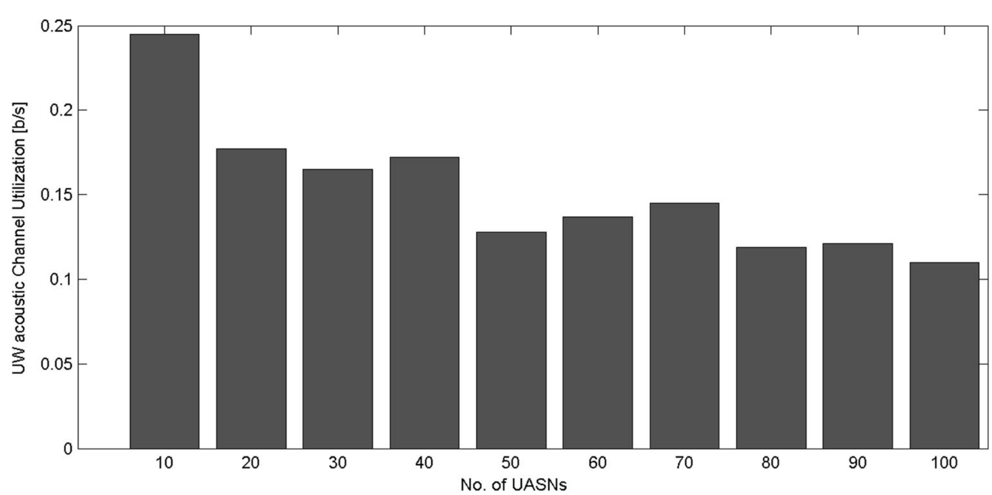

Fig. 8 Underwater acoustic bandwidth utilization for various network sizes

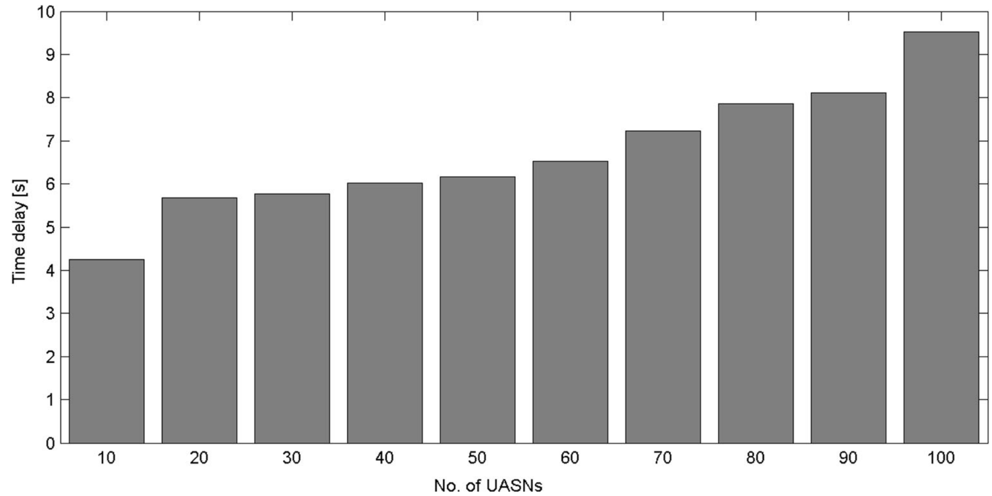

Fig. 9 Average time delay for different network sizes

Average time delay is calculated by

$$\eta = \frac{Y}{X}\sum_{i=1}^{Y}\left[\frac{1}{\sum_{j=1}^{Y}\left(\mathrm{TDMA\_MAT_{ij}}\right)}\right] \tag{4}$$

The average time delay for each node in UWASN represents the average availability of the network, and the minimal turnaround time is very important for the optimal underwater network design.

5 Simulation results for underwater broadcast scheduling

The simulation results are carried out using MATLAB, based on the following parameters shown in Table 1, and the number of UASN is varied from ten to hundred. On running the simulation as given in the simulation setup, it is observed that for ten-node UWASN, the GA-TDMA takes only five time slots to schedule for node transmissions, whereas in HSR-TDMA, it takes ten time slots to schedule for node transmissions as shown in Fig. 6. This shows that GA-TDMA has optimal node scheduling with a minimum of one transmission for every node in the network. Also as seen in Fig. 6, it is observed that nodes 9 and 10 in HSR-TDMA have transmitted only once in the second and fifth time slot that shows that it has to wait for ten time slots for its next transmission. This long turnaround wait time leads to the low successful packet transmission rate for those nodes, whereas in GA-TDMA, every node in the UWASN has an average minimal turnaround wait time of five time slots. Table 2 shows that as the number of nodes in UWASN increases, HSR-TDMA frame length also increases, whereas in GA-TDMA, optimum frame length is maintained for various sizes of network. In each generation of the genetic algorithm, the fitness is evaluated.

GA is run for 50 times and the average value of simulation result is shown in Table 3. It was observed that a maximum

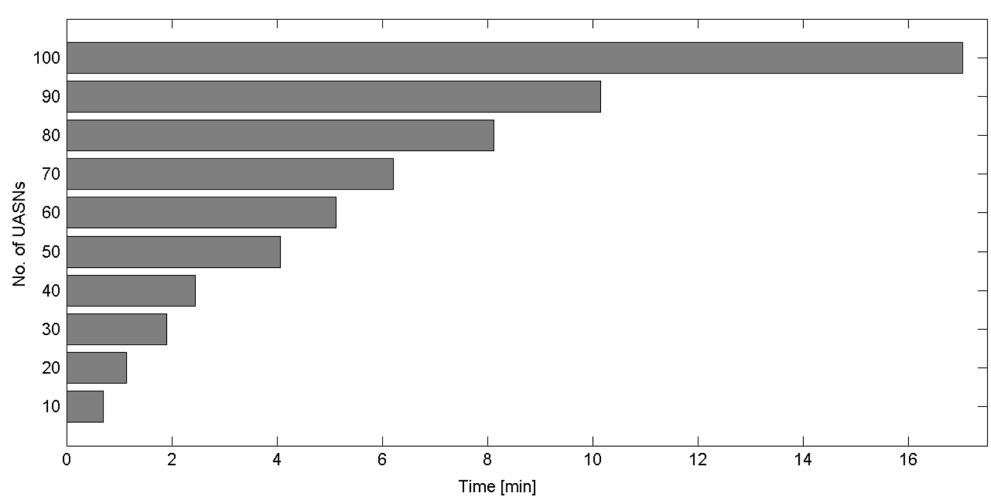

Fig. 10 Computation time taken by GA for various network sizes

node degree [ND] in the network has impacted the optimal TDMA frame length with the help of tight lower bound after the average GA run. As shown in Fig. 6, it is also observed that the nodes 1 and 10 in GA-TDMA transmitted twice within five time slots which shows the utilization of available acoustic sensor bandwidth has been done in underwater by scheduling the possible nodes for parallel transmission. In comparison of GA with HSR and traditional approach, it was analyzed that for ten-node network, a throughput shown in Fig. 7 increases with the increase in transmission cycle. This proves that GA-TDMA has rapidly increased its throughput for UWASN as the cycle of transmission increases, and it overcomes HSR and traditional approach. Figures 8 and 9 show the underwater channel utilization and average time delay of various network sizes in underwater based on Eqs. (3) and (4). It is observed that the average time delay is getting increased as the size of the network gets increased. The underwater acoustic channel utilization is based on the connectivity of the network that is shown in Fig. 8. Figure 10 shows the computation time taken by the GA for various network sizes. It is also been observed as the number of nodes increases, the computation time taken by GA also increases. Therefore, the simulation result for various simulation scenarios proves that GA-TDMA outperforms HSR-TDMA in turnaround wait time.

6 Conclusion

Using genetic algorithm, the TDMA frame for underwater acoustic sensor network has been optimized in this study. In each generation of GA, different TDMA frame lengths have been achieved with at least one chance for each node to transmit in underwater. GA-TDMA minimizes the time slots to avoid the maximal turnaround waiting time of successive node transmission even for sizes of large networks. GA-TDMA also schedules the possible nodes for parallel transmission in the optimal TDMA frame to improve the utilization of available acoustic bandwidth in underwater. The result shows that higher throughput in the UWASN is achieved that outperforms the spatial reuse HSR-TDMA scheduling method. Finally, the efficiency and effectiveness of GA for node scheduling are validated with this outcome. Further research is required to improve upon the GA to reduce the computation time by finding variations of crossover and mutation.

References

1. https://www.popsci.com/article/technology/underwater-gliders-gather-data-help-predict-next-big-storm. Accessed 19 Sep 2016
2. Che X, Wells I, Dickers G, Kear P, Gong X (2010) Re-evaluation of RF electromagnetic communication in underwater sensor networks. IEEE Commun Mag 48(12):143–151
3. Farr N, Bowen A, Ware J, Pontbriand C, Tivey M (2010) An integrated, underwater optical/acoustic communications system. IEEE OCEANS Sydney, pp 16
4. Heidemann J, Stojanovic M, Zorzi M (2012) Underwater sensor networks: applications, advances and challenges. Philos Trans R Soc 370:158–175
5. Akildiz IF, Pompili D, Melodia T (2005) Underwater acoustic sensor networks: research challenges. Ad Hoc Networks 3:257–279
6. Akyildiz IF, Wang P, Lin S-C (2016) SoftWater: software-defined networking for next-generation underwater communication systems, Ad Hoc Networks
7. Hong L, Hong F, Guo Z, Li Z (2011) ECS: Efficient Communication Scheduling for underwater sensor networks. Sensors 11(3):2920–2938
8. Pu L, Luo Y, Mo H, Peng Z, Cui J-H, Jiang Z (2013) Comparing underwater MAC protocols in real sea experiment, IFIP Networking Conference
9. Partan J, Kurose J, Levine BA (2006) A survey of practical issues in the underwater networks, International conference on Mobile computing and Networking (Mobicom), Los Angeles, CA, USA Sep (2006)
10. Akyildiz IF, Pompili D, Melodia T (2006) State of the art in protocol research for underwater acoustic sensor networks, ACM International workshop on underwater networks (WUWNet), Los Angeles, CA, USA Sep (2006)
11. Xie P, Cui JH (2006) Exploring random access and handshaking techniques in large-scale underwater wireless acoustic sensor networks, OCEANS
12. Climent S, Sanchez A, Capella JV, Meratnia N, Serrano JJ (2014) Underwater acoustic wireless sensor networks: advances and future trends in physical, MAC and routing layers. Sensors 14(1):795–833
13. Hong L, Hong F, Guo Z, Li Z (2011) ECS: efficient communication scheduling for underwater sensor networks. Sensors 11:2920–2938
14. Chitre M, Shahabodeen S, Stojanovic M (2008) Underwater acoustic communications and networking: recent advances and future challenges. Mar Technol Soc J 42:103–116
15. Huang P-H, Chen Y, Krishnamachari B (2010) Anilkumar, Link scheduling in a single broadcast domain underwater network, IEEE International Conference on Sensor Networks, Ubiquitous and Trust worth computing (SUTC), Newport Beach, CA, USA June (2010), pp. 205–212
16. Lee JW, Cho HS (2014) Cascading multi-hop reservation and transmission in underwater acoustic sensor networks. Sensors 14: 18390–18409
17. Diamant R, Lampe L (2011) Spatial reuse TDMA for broadcast ad-hoc underwater acoustic communication networks. IEEE J Ocean Eng 36:172–185
18. Bharathi C, Rekha D, Vijayakumar V (2017) Genetic algorithm based demand side management for smart grid. Wirel Pers Commun 93:481–502
19. Sivakumar V, Rekha D (2018) Underwater acoustic sensor node scheduling using an evolutionary memetic algorithm. Res J Telecommun Inf Technol 1:88–94
20. Hong L, Hong F, Guo Z, Yang X (2008) A TDMA-based MAC protocol in Underwater Sensor Networks, IEEE conference on wireless communication, Networking and Mobile Computing (Wicom) Oct (2008), pp. 1–4
21. Anjangi P, Chitre M (2015) Design and implementation of super TDMA: a MAC protocol exploiting large propagation delays for underwater acoustic networks, ACM International Conference on Underwater Networks and System (WUWNET),Washington DC, USA, Oct (2015)

22. Kredo K, Djukic P, Mohuputra P (2009) STUMP: exploiting position diversity in the staggered TDMA underwater MAC protocol, IEEE conference on computer communications (Infocom), Rio De Janeiro, Brazil, Apr (2009)
23. Hsu C-C, Lai K-F, Chou C-F, Lin K C-J (2009) ST-MAC: spatial-temporal MAC scheduling for underwater sensor networks. In: Proceedings of IEEE InfoCom, Rio de Janeiro, Brazil, 1925, pp. 1827–1835
24. David E (1997) Goldberg, genetic algorithms in search. Optimization and machine learning. Addison Wesley
25. De Jong KA, Spears WM (1989) Using genetic algorithm to solve NP-complete problems, Proceedings of 3rd International Conference on Genetic Algorithms Jan (1989), pp. 124–132