EAI Endorsed Transactions
on Internet of Things Research Article **EAI.EU**

Efficient Resource Allocation Design for Mitigating Multi-Jammer in Underwater Wireless Sensor Network

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Abstract

Underwater wireless sensor networks (UWSNs) are used for monitoring costal area and military surveillance applications, for example tsunami prevention and target tracking etc. Jamming is considered to be a serious problem in UWSNs where the intruder affects the lifetime of sensor motes and impact the packet transmission performance. This paper consider that the jammer device has capability of reducing battery lifetime and preventing communication of trustworthy UWSN mote. Existing resource utilization model are not efficient considering presence of multiple jammers. For overcoming research issues this work present efficient resource allocation design for mitigating multiple jammers in UWSNs. The ERA model adopts cross layer design and can communicate in cooperative manner using direct and hop based communication that maximize resource utilization quality specifier. Experiment outcome shows the ERA achieves much better detection rate, resource utilization, packet drop, and energy efficiency performance compared with existing resource allocation methodologies considering presence of multiple jammer motes.

Keywords: Cooperative communication, Cross layer design, Energy efficiency, Lifetime, Reactive Jamming, UWSN

Received on 02 December 2020, accepted on 04 February 2021, published on 08 February 2021

doi: 10.4108/eai.8-2-2021.168688

1. Introduction

Wireless communication in underwater scenarios is very challenging such as extreme attenuation makes communication possible only with short-range broadband channels using microwave bands [1], [11]. For increasing the communication range acoustic wave are used for communication in underwater communication environment. However, these signals are highly affected due to presence of noise presence in underwater environment such as shipping activities, marine life, and wind. Along with, it is affected because of narrow band, multipath fading, reflection, and propagation delay etc. Despite such complicated condition of propagation scenarios, underwater wireless sensor network (UWSN) is used by different industries, and military applications. Further, it is also used for monitoring tsunami and soil erosion. Considering these applications, it is important to provide efficient security mechanism as it is used for monitoring environment and surveillance. A Denial of-service (DoS) or jamming attack can have catastrophic magnitudes for the compromised system, which already faces the challenges of a hostile environment [2] [3].

Jamming is firmly defined as the specific interference induced in wireless network through the malicious nodes by reducing the signal-to-noise ratio of receiver side through transmission of interfering wireless signals; further it is observed that jamming is different from the interference or regular noise since it causes the degrade in network performance. Jamming is induced at various level i.e., from hampering communication to alter information in given legitimate communication. Furthermore, to understand the attack on underwater-WSN or to avoid the jamming for efficient communication. There are different types of jammer such as reactive jammer, proactive jammer, hybrid smart jammer and function specific jammer; further it is very important to know the jammer types to attain the optimal placement of jammer. Hence many existing methodologies have been considered through the various researcher and various strategy has been designed to address the issue of jamming [5]. Moreover, reactive jammer is the

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type of jamming where jammer remains silent until authentic initialization of the sensor device takes place over the given channel; this is one of the general jamming and used widely; it requires absolute strong mechanism and efficient mechanism [6], [7] to protect and detect respectively.

Extensive survey shows that the existing resource allocation or channel access methodology presented so far to mitigate jamming effect are only effective in terrestrial WSN [8], [9], [10]. Further, MAC layer optimization model [5], [13], [19] has been carried out to improve by resource utilization. In [12] routed packet on pre-selected path as a result they are not efficient under highly dynamic jamming attack environment. Further, in [15], [16] a cooperative communication scheme has been presented to utilize resource more efficiently [11], [14]. Further, [17] showed adopting cross layer design for selecting hop motes aid in improve UWSN resource. However, the main drawback of these models was that they failed to achieve the efficient resource utilization since they avoided the spatial re-use. In [18] developed a spatial reuse mechanism considering mitigating near far node effects [20], [21], [22], but ignored proper scheduling as well as delay in transmission, hence there is a higher probability of packet collision. Further, these models are designed considering presence of single jammer scenarios. Thus, this paper present efficient resource allocation (ERA) for mitigating multi-jammer adopting cross layer architecture in UWSN.

The significance of efficient resource allocation for mitigating multi-jammer in UWSN are as follows

- First this paper presents a highly dynamic reactive jamming effect model.
- Second presented resource maximization strategy considering presence of both direct and hop communication.
- Third presented a bounding model for solving resource maximization problem with presence of multiple user and multiple jammers.
- Experiment outcome shows the proposed methodology reduces packet drop, improve resource utilization and improves energy efficiency of UWSN.

The manuscript is structured as follows. In section II, the efficient resource allocation model for mitigating multiple jammers in UWSN is presented. The result achieved by ERA over existing resource allocation model is discussed in section III. Last section the work is concluded and future improvement of work are discussed

2. Efficient resource allocation designing for underwater wireless sensor

This section present efficient resource allocation design for mitigating multi-jammer in UWSN. First this work adopts cross layer design presented in our previous work [26], [27]. Second discusses about the resource maximization problem with presence of multiple jammers in UWSN. Lastly, present an optimal strategy for improving packet transmission and energy efficiency of UWSN.

2.1. System Model, Reactive jamming and cross layer design model

Let assume a UWSN with O trustworthy underwater motes where these motes can communicate with each other [26], [27]. Further there are G orthogonal frequency channels using which the underwater motes will communicate among themselves. Further, there are k number of jamming motes presented in network. These jammer motes possess limited power for carrying out jamming effect to reduce the performance of trustworthy motes. The jammer motes power has capability of affecting or jamming all the available channel in UWSN can be described using following equation

$$q_k = \left(q_k^g\right)_{g\in G}, \tag{1}$$

where q_k^g describes power specified on certain channel g which can be defined as follows

$$X^U q_k \le q_k^{\uparrow}, \tag{2}$$

where X represent an $X * |O|$ vector of 'X', and $q_k^{\uparrow}$ depicts jammer mots maximal power capability for carrying out jamming effects in UWSN. Therefore, the reactive jamming strategy can be described using following equation

$$q_k^g = \frac{E_k^g}{\sum_{g\in G} E_k^g} * q_k^{\uparrow}, \forall g \in G. \tag{3}$$

where E_k^g represent the sensed noise and interference level k on channel g.

This work considers a multihop based UWSN communication where sensor device cooperatively transmits its packet to the destination through intermediate nodes within its communication range similar to [26], [27]. Here the hop motes is selected at each time slots. The UWSN motes that does not carry out any sensing operation on particular slot time are selected as hop motes for other UWSN mote for carryout transmission in optimal and cooperative manner. The UWSN mote optimistically access spectrum by maximizing the channel access probability of jammed motes and transmit packet. For maximizing channel access probability, the contention window parameter of slotted multichannel CSMA is modified. For keeping collision probability less, in this work the contention window (CW) is kept sufficiently large. Let consider r_o^g, $g \in G$ describing the channel sensing probabilities of UWSN mote o on channel g and then the UWSN mote might incur certain delay for carrying out communication for being as an intermediate UWSN mote for neighboring mote due to nonzero probability of node o. Thus, we have

$$\sum_{g\in G} r_o^g \leq 1. \tag{4}$$

2.2. Efficient resource design for mitigating multiple jammers in UWSN

This section present efficient resource allocation design for mitigating multi-jammer in UWSN. This work uses channel accessible probability as the policy space of a trustworthy UWSN mote and can be represented as follows

$$r_o = \left(r_o^g\right)_{g\in\tilde{G}} \tag{5}$$

with

$$\tilde{G} = G \cup \{0\}, \tag{6}$$

where r_o^g represent the channel accessing probabilities of channel g, and r_o^0 represent the probabilities that o doesn't checks for any accessibility of the UWSN channels. In such case the model assures following constraint described in Eq. (7), (8), and (9).

$$r_o^g > 0, \forall o \in O, \forall g \in \tilde{G} \tag{7}$$

$$r_o^g \leq 1, \forall o \in O, \forall g \in \tilde{G} \tag{8}$$

$$X^U r_o = 1, \forall o \in O. \tag{9}$$

The trustworthy UWSN motes size that belongs to $o \in O$ can be estimated using following equation

$$D_o(r, q_k) = \sum_{g\in G} r_o^g \beta_o^g(r, q_k) D_o^g(r, q_k), \tag{10}$$

where $\beta_o^g(r, q_k) D_o^g$ defines success probabilities of UWSN motes o channel accessibility, r_o^g defines probabilities of channel accessibility sensing, and $D_o^g(r, q_k)$ describes actual available channel size through both mode (i..e, direct and though hop) of communication with presence of jamming effects q_k and channel sensing probabilities r.

The anticipated traffic through direct communication is obtained using following equation

$$D_{o,g}^{direct}(q_k) = C \log\left(1 + \mu_{o,g}^{t2e}(q_k)\right), \tag{11}$$

where C represent bandwidth of different frequency channel, and $\mu_{o,g}^{t2e}(q_k)$ is computed as follows

$$\mu_{o,g}^{t2e}(q_k) = \frac{q_o I_o . \left(h_o^g\right)^2}{\left(\varphi_{e(o)}^g\right)^2 + q_k I_{ke(o)} . \left(i_{ke(o)}\right)^2} \tag{12}$$

where q_o depicts UWSN mote o communication power level, I_o^g represent fading parameter of the operating channel environment and I_o represent the path loss of the operating channel environment, $\left(\varphi_{e(o)}^g\right)^2$ depicts receiver side noise $e(o)$ on particular frequency channel g.

In similar manner to direct communication the cooperative hop-based communication can be established. Let consider that every mote that wants to transmit a packet will have $n \in O/o$ as a hop device with probabilities of r_n^0. Therefore, the cooperative hop motes is established using following equations

$$D_{o,g}^{coperative}(q_k) = \frac{C}{2} log\Big(1 + \min\left(\mu_{on,g}^{t2s}, \mu_{o,g}^{t2e} + \mu_{no,g}^{s2e}\right)\Big) \tag{13}$$

where $\mu_{on,g}^{t2s} = \mu_{on,g}^{t2s}(q_k)$ represent signal to noise ratio (SNR) between source motes and the cooperative hop motes and $\mu_{no,g}^{s2e} = \mu_{no,g}^{s2e}(q_k)$ represent SNR between the cooperative hop motes and the destination motes. Thus, the total anticipated capacity accessible by UWSN mote o on particular frequency channel g is obtained using following equation

$$D_o^g(r, q_k) = \left(\sum_{n\in O/o} D_{o,g}^{coperative}(q_k) + \sum_{n\in O/o} D_{o,g}^{direct}(q_k)\right) \tag{14}$$

For every source mote there could be multiple hop motes or path to transmit a packet. This work aims at maximizing resource utilization objectives which can be described using following equation

$$(r, q_k) = \log\left(D_o(r, q_k)\right), \tag{15}$$

and the proposed quality specifier parameter to maximize the resource utilization of sensor device without affecting another legitimate sensor device can be expressed as follows

$$Given:\ q_k \tag{16}$$

$$\underset{r\in(0,1)^{|O|}}{\text{Maximize}}\, V_o(r, q_k) = \sum_{o\in O} V_o(r, q_k)$$

$$Subject\ to: (7), (8), (9)$$

For improving efficiency of resource allocation methodology, the Eq. (16) constraint are solved. Let consider V^* as a global optimal solution problem, and $\varepsilon \in [0,1]$ as predefined optimal solution. Thus, the quality specifier of proposed resource allocation is to assure ε −optimal strategy r assuring

$$V(r) \geq \varepsilon V^*. \tag{17}$$

Here, the ε can be configured as closer to 1 at the higher computation overhead. Let define $\mathcal{U}_g$ as upper limits of global solution and $\mathcal{L}_g$ represent as lower limits of global solution with respect to resource maximization function defined in Eq. (16). Then it can be defined as follows

$$\mathcal{L}_g \leq V^* \leq \mathcal{U}_g. \tag{18}$$

Then, the proposed methodology searches for $\varepsilon -$optimal strategy in iterative manner by optimizing $\mathcal{L}_{g}$ and $\mathcal{U}_{g}$. This is done for assuring that both limits get closer among them, until

$$\mathcal{L}_{g} \geq \varepsilon . \mathcal{U}_{g} . \qquad (19)$$

In this way the proposed efficient resource allocation methodology under presence of multiple jamming nodes attains superior performance than state-of-art model which is experimentally proved in next section below.

3. Simulation and Result Analysis

This section discusses about the experimental setup and simulation parameter, performance metric used for analyzing outcome achieved by distributed resource allocation model over existing resource allocation model [18] under presence of multiple jamming sensor devices. MAcoSim simulator is used for carrying out performance evaluation [23], [24], and [25]. Experiment is conducted by varying sensor mote size of 50, and 100. These motes are placed randomly across UWSN with size of 16m*16m. Further, the jammer mote size is varied from 4, 6, and 8 and placed within 16m*16m area. Each jammer will transmit 8 bits of packet for a give slot and each mote will generate traffic in UWSN by transmitting 3 bits of packets. Total 100 iteration is considered for obtaining simulated outcomes and performance achieved is estimated using resource utilization, packet drop rate, energy efficiency, and detection rate.

Figure 1 show the resource utilization performance achieved by ERA considering varied jammer mote size. From result it can be seen when jammer mote size is 4 and 8 the total CTS packet sent is 129 and 129. Then when jammer mote size is 4 and 8 the total RTS packet sent is 41 and 41. Similarly when jammer mote size is 4 and 8 the total packet received correctly is 35 and 34. From result it can be seen on an average considering varied jammer mote size 41 RTS packet is sent in a UWSN network out of which 35 packets have been successfully received at the receiver side. From this we can interpretive that there is 15.85% duplicate packet generated by jammer is being circulated in UWSN environment.

Figure 2 shows packet transmission performance achieved by proposed-by-proposed ERA model with presence of multiple jammer size of 4 and 8 keeping UWSN mote size to 100 and experiment is conducted. From experiment it is seen when jammer mote size is 4 and 8 the number of sent packet is 161 and 163, respectively. Then, when jammer mote size is 4 and 8 the number of dropped packet is 84 and 108, respectively. Then, when jammer mote size is 4 and 8 the number of received packet is 133 and 135, respectively. Similarly, when jammer mote size is 4 and 8 the number of discarded packets is 120 and 124, respectively. From result it can be seen as jammer mote size increases packet being dropped is increasing, very limited work is carried out by existing methodologies for evaluating performance considering presence of multiple jammers. This, work is first of kind to evaluate such kind evaluation considering presence of multiple jammers in UWSN environment.

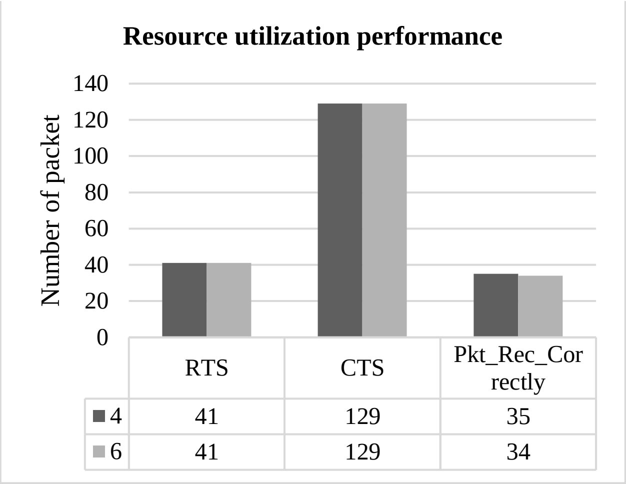

Figure 1 Resource utilization performance considering varied number of jammer device.

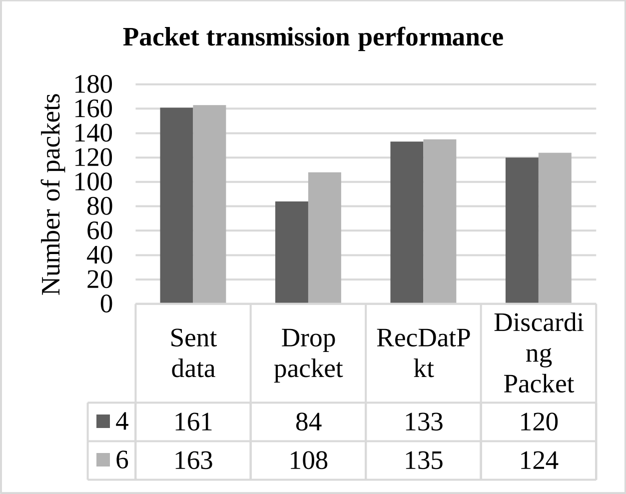

Figure 2 Packet transmission performance considering varied number of jammer device

Figure 3, Figure 4 and Figure 5 shows energy efficiency performance achieved by proposed ERA with and without presence of jammer motes considering varied jammer mote size, varied sensor mote size, and varied slot size. First experiment is conducted by varying jammer mote to 4 and 8 keeping slot size and mote size constant of 5 μs and 100, respectively and average energy consumed with and without jammer mote is noted and graphically shown in Fig. 3. From Fig. 3 it is seen an average energy overhead of 10.64% is achieved by ERA with presence of jammer mote when compared with ERA without presence of jammer mote considering varied jammer mote size.

Second experiment is conducted by varying mote to 50 and 100 keeping slot size and jammer mote size constant of 5 μs and 8, respectively and average energy consumed with and without jammer mote is noted and graphically shown in Figure. 4. From Figure 4 it is seen an average energy overhead of 9.737% is achieved by ERA with presence of jammer mote when compared with ERA without presence of jammer mote considering varied mote size.

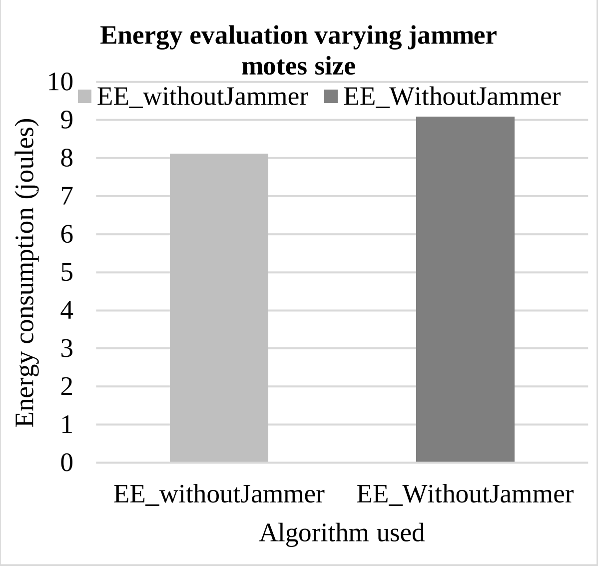

Figure 3 Energy efficiency performance considering varied number of jammer motes.

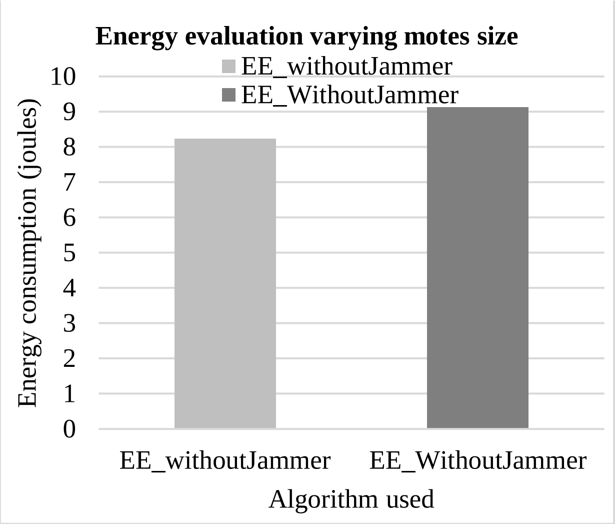

Figure 4 Energy efficiency performance considering varied number of UWSN motes.

Third experiment is conducted by varying slot size to 5 μs and 10 μs keeping mote and jammer mote size constant of 100 and 8, respectively and average energy consumed with and without jammer mote is noted and graphically shown in Figure 5. From Figure 5 it is seen an average energy overhead of 3.96% is achieved by ERA with presence of jammer mote when compared with ERA without presence of jammer mote considering varied slot size.

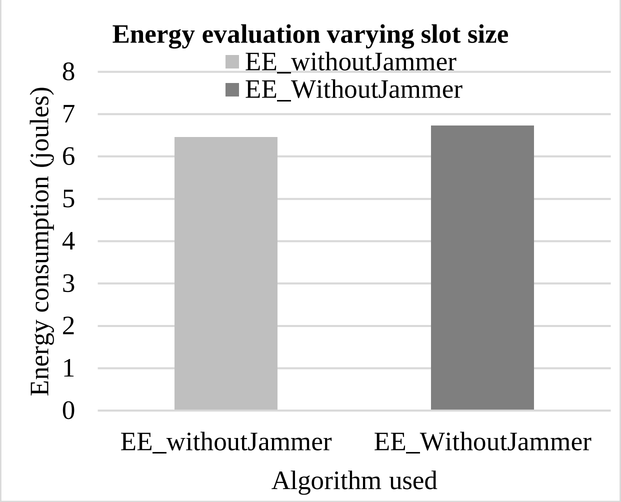

Figure 5 Energy efficiency performance considering varied slot size.

To show the ERA model achieves much superior outcome that existing methodologies [18]; a comparative analysis is shown in Table 1. From Table 1 it can be seen the proposed ERA model achieves much superior outcome than existing resource allocation considering presence of multiple jammers.

Table 1: Performance comparison of DRA with respect to existing resource allocation model [18] under UWSN environment

	DRA Performance	
	[18]	Proposed ERA
Drop Rate	33.33%-57.15%	1.62-6.81%
Detection Accuracy		90.39%
Resource Utilization	90.0%	95.46%
Energy overhead		8.11%

4 Conclusion

This work presented efficient resource allocation model for jammed UWSN user under presence of multiple jammer mote. The ERA model can detect jammer node more efficiently and allocate resource to jammed node in more optimal fashion meeting resource maximizing constraint. Further, cooperative cross layer design keeping contention window size higher aided in utilizing resource more efficiently. From result achieved it can be seen the ERA model achieves packet drop rate of 1.62%-6.81 where existing methodologies achieves a drop rate of 33.33%-57.15%. Further, existing methodologies achieves resource utilization 90% where the ERA achieves a resource utilization performance of 95.46%. Then detection rate of 90.39% is achieved by proposed ERA method. Further, the proposed ERA induces energy overhead of 8.11% considering varied mote, jammer mote, and slot size which is negligible considering resource utilization performance achieved by ERA. Further, no prior work has considered such energy performance evaluation. From result achieved it can be sated the ERA is very efficient when adopted under highly dynamic jamming environment with presence of multiple jammers. Future work would consider employing more heuristic and optimal solution to further enhance of lifetime UWSN sensor motes.

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