Instantaneous channel characteristics and progression factor based collaborative routing

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Article Info

Article history:

Received Mar 9, 2022
Revised Jul 12, 2022
Accepted Aug 12, 2022

Keywords:

Collaborative routing
Energy consumption
Progression factor
Propagation delay
Transmission loss
Underwater sensor network

ABSTRACT

Underwater acoustic sensor networks (UWASN) have enormous applications like investigating oceanographic environment, data gathering, scrutiny, calamity avoidance etc. Cooperative communication becomes mandatory when nodes are distributed far apart especially in the ocean environment. The existing relay selection techniques do not consider the instantaneous channel characteristics while selecting the relay nodes. The relays selected based on the outdated channel state information aggravates or worsens the performance of the rapidly changing or dynamic UWASN. Hence, this paper proposes an instantaneous channel characteristics and progression factor (ICPF) based collaborative routing for underwater acoustic sensor networks. It considers numerous indexes such as propagation delay, residual energy, progression factor, spreading, transmission and absorption loss in the forwarding relay node selection. These indexes are averaged and updated periodically to overcome the difficulties caused by the inconsistency and aggressive nature of underwater channel. The progression factor proposed in this work is a prime metric that facilitates efficient data forwarding. Simulation results show that the proposed technique outperforms the existing schemes in terms of packet delivery ratio (PDR), average end to end delay and energy consumption and is capable of achieving PDR of 90.1% for network comprising of 100 acoustic nodes.

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1. INTRODUCTION

Underwater acoustic sensor network (UWASN) consists of abundant acoustic sensor nodes, unmanned underwater vehicles (UUV) and surface marker buoys (SMB) that collectively observe the aquatic region. Acoustic nodes are randomly distributed [1] at vacillating pressure levels depending on the category of application. The drifting of acoustic nodes in the subsea environment is caused by oceanic forces and ocean currents [2]. In the recent years, UWASN have gained enormous attention because of its remarkable characteristics and applications in the investigation of beneficial oceanic resources and oceanic ecosphere [3]. It can discern temblors from isolated regions and impart cautions to seaside thereby averting catastrophes [4]. UWASNs are capable of recognizing the perils in the aqueous environment and aids in shipping [5]. It oversees the regions for diplomatic observance and gives circumstantial evaluation.

Various researches have been carried out in UWASN which are discussed in this section. Yan *et al*. [6] proposed a depth based routing (DBR) where each acoustic node estimates its depth value and collates along the sender. If the estimated value is larger, it averts its own data transmission. The forwarders are efficiently chosen with minimal complexity. The main drawback is the requirement of depth sensor which subsequently increases the cost of data transmission.

The integration of three heuristic techniques in relay selection is proposed in [7]. It constantly immigrates the intermediate forwarders to pertinent locations for prolonging the network life time. It balances the energy expenditure by amending the flow of traffic. The main drawback is its increased time complexity.

Bit error rate (BER) based relay selection approach is proposed by Doosti-Aref and Ebrahimzadeh [8]. The intricacy of this approach augments along the aggregate subcarriers. The disadvantage of (BERB-ORS) is that the chaotic discrepancies of acoustic medium are ignored. An energy-efficient multipath routing (EEMR) [9] is destined for curtailing energy expenditure and for elongating network longevity. It effectively forbids flooding and doesn't need any positional information. EEMR organizes a priority table for selecting the acoustic nodes to take part in routing. The main drawback is the higher delay that is encountered in EEMR.

Void hole avoidance routing algorithm proposed in [10] utilizes a linked tree for estimating the deepness of sensor nodes from surface. Its routing course is precisely defined for the transference of data from sender to sink. The deployed depth of the acoustic nodes in the aqueous environment is concerted among them to alleviate the void region. Optimal transmitter is obtained by taking the downward distance from sea surface, energy, waiting time and length to next hop sensors. Inclusion of optimization scheme increases the network complexity.

In ant colony algorithm based routing (ACAR) [11], the path amidst source and the destination nodes is created using ACO which lessens the overall network delay. ACAR uses combined communication approach for minimizing the energy expenditure for the acoustic nodes that broadcast regularly. The hop value and the remaining energy of acoustic nodes are used for estimation of pheromone. An intricate analysis of acoustic node distribution approaches in the aquatic environment, diverse UWASN applications and routing algorithms is carried in [12]. The predominant classification of acoustic node distribution such as stationary, self-adapated and motility aided node distribution are scrutinized. Various georouting and Nongeo routing schemes with its pros and cons are analyzed.

Radius based courier node routing for underwater acoustic sensor network is proposed in [13]. Initially, the network space is partitioned as space for destination and space for sink. It collaborates the range along depth level, tracking-ID, functional cost and energy of acoustic nodes. It is mainly designed for comprehensive monitoring with low energy usage and higher PDR. Fast recovery algorithm and dynamic topology management is necessary to enhance its performance.

Nazareth and Chandavarkar [14] for prohibiting void nodes from taking part in the data transmission process. This is achieved by creating void awareness amidst acoustic nodes. It is evaluated by taking the number of accessible transmitters to sink and number of inaccessible transmitters due to looping towards sink, Euclidean distance and average hop count. An effective strategy for elongating the network life time and to curtail the energy expenditure is proposed in [15]. In the beginning phase, the prime motive is to detect the optimal cluster head for each phase on varying inception point and to regulate energy amidst group of nodes. It is followed by effective TDMA rescheduling that facilitates consistent data forwarding amidst sensors. It does not have any mechanism to provide data privacy and security.

In energy-aware and void-avoidable routing protocol proposed in [16], concentric shells are created encompassing sink followed by the dissemination of sensors on diversified shells in the layering phase. In the data collecting phase, packets are forwarded greedily towards numerous concentric shells. An energy and depth variance-based opportunistic void avoidance technique for underwater acoustic sensor networks (EDOVE) [17] uses the residual energy and depth difference amidst sensors for the estimation of waiting time. It facilitates uniform energy distribution and balanced data forwarding in the entire network. The main drawback of EDOVE is that it has higher delay because it concentrates on energy and load balancing than the greedy data transmission towards sink.

A fuzzy logic vector based forwarding approach proposed in [18] makes use of the residual energy, Euclidian distance amist source and sink and the projection point that defines the contiguity to the pipe for choosing the subsequent forwarder. The prime drawback is its increased routing overhead in the cylindrical vector. A comprehensive study of throughput for chaotic distributed sensors in the aquatic environment is made in [19]. Simulation results infer that extremely high overhead leads to higher network delay. The detailed study demonstrates the methodologies to acquire the actual trade-off between capacity and delay.

Energy hole and coverage avoidance routing (EHCAR) proposed in [20] prevents the energy hole problems along with the coverage hole restoration schemes. In the high density network, coverage of acoustic nodes imbricate regularly. EHCAR acquire the advantages of repeated overlapping to restore the issues of coverage holes. Robust transmitting layer multipath power regulation based routing proposed in [21] minimizes the energy consumption and accomplish data accuracy. It is successfully carried out by utilizing tree topology for guiding the packets towards the sea surface. Energy consumption is minimized considerably by choosing route with minimal noise between source and sink. The main drawback is its increased delay.

Localization-free interference and energy holes minimization (LF-IEHM) technique proposed in [22] knock over the interventions in the data forwarding by specifying an exclusive waiting time for each node. When compared with the traditional routing schemes, LF IEHM is free from the necessity of obtaining the geographic coordinates. It is hard and burdensome to calculate as the acoustic nodes are prone to drifting, with respect to aggressive oceanic forces.

Normalized advancement based totally opportunistic routing algorithm (NA-TORA) proposed in [23] chooses the adjoining transmitters by computing a parameter called normalized advancement (NA) estimated from expected transmission count (ETX) and energy utilization. The occurrence of void regions hinders the reception of packets at the destination node which is solved by integrating Void Avoidance schemes. Its drawback is that, the drifting of nodes due to oceanographic forces is not considered. The existing relay selection techniques and routing protocols do not take the instantaneous channel characteristics [24] and the selection of relay nodes is based on the outdated channel state information. This worsens the performance of dynamic underwater acoustic sensor network.

Therefore, the eminent contributions of proposed ICPF technique are: i) ICPF technique considers numerous quality indicators such as propagation delay, residual energy, transmission, spreading and absorption losses, in the relay selection process. ii) Progression factor computation of nodes in the relay selection plays a critical role in enhancing the data forwarding in UWASN. iii) To overcome the difficulties caused by the inconsistency and aggressive nature of underwater channel, these parameters are averaged and updated periodically in the associate node table. vi) Simulations of the proposed instantaneous channel characteristics and progression factor (ICPF) based collaborative routing is carried out and analyzed in terms of average energy consumption, end to end delay and PDR. From the performance evaluation, it is inferred that ICPF technique surpasses the existing schemes. The rest of manuscript is organized as shown in: Section 2 illustrates the proposed ICPF based collaborative routing for UWASN, section 3 illustrates the simulation results of ICPF technique and section 4 describes the conclusion of this research paper.

2. PROPOSED METHOD

Instantaneous channel characteristics and progression factor (ICPF) based collaborative routing is proposed to select efficient intermediate relay nodes to enhance the data transmission to the destination. The link quality indicators utilized for relay selection process are propagation delay, residual energy, transmission, spreading and absorption losses. These indicators are precisely explained in next sub-section.

2.1. Propagation delay

Propagation delay can be defined as the time taken by the acoustic signal to transmit from source node to destination node in the subsea environment [25]. It is computed from the nodal distance and speed of sound in water medium as shown in (1),

$$P_{delay} = \frac{d}{c} \tag{1}$$

where, d is distance between two nodes in meters and the average velocity of sound in water is c which is approximated as 1500 m/s.

2.2. Transmission, spreading and absorption losses

Transmission loss is the reduction in the strength of the sound as it traverses from the source node to the destination node in the acoustic network [25]. Transmission loss in (dB) is given by (2),

$$TL = SS + \alpha \times 10^{-3} \tag{2}$$

where, α is attenuation factor in dB and SS is spherical spreading factor. Attenuation factor in (dB) is given by (3),

$$\alpha = 0.11\frac{f^2}{1+f^2} + 44\frac{f^2}{4100+f^2} + 2.75 \times 10^{-4}f^2 + 0.003 \tag{3}$$

where, f is the frequency of sound.

Spreading loss is a category of transmission loss that fulminates when the acoustic wave travels away from sender node to receptor node [25]. With the increase in transmission range (T), there is corresponding increase in Spherical spreading factor which is given by (4).

$$\mathrm{SL} = 20\log(\mathrm{T}) \quad (4)$$

Absorption loss is dependent on attenuation factor and transmission range which is expressed in (5).

$$\mathrm{AL} = \alpha \times \mathrm{T} \times 10^{-3} \quad (5)$$

Here, T is transmission range in meters and α is attenuation factor in dB.

2.3. Residual energy

The residual energy [26] is calculated from (6).

$$\mathrm{E_{Residual}} = \mathrm{E_{Initial}} - (\mathrm{E_{fwd}} \times \mathrm{N_{fwd}}) - (\mathrm{E_{ack}} \times \mathrm{N_{control}}) - (\mathrm{E_{rec}} \times \mathrm{N_{rec}}) - (\mathrm{I} \times \mathrm{E_{idle}}) \quad (6)$$

Where, $\mathrm{E_{Initial}}$ represent the initial energy, $\mathrm{E_{fwd}}$ and $\mathrm{E_{rec}}$ denote the energy needed for data forwarding and reception ($\mathrm{E_{fwd}}$>$\mathrm{E_{rec}}$). $\mathrm{N_{fwd}}$ and $\mathrm{N_{rec}}$ denote forwarding and reception packet count. $\mathrm{E_{ack}}$ represents the energy for sending an acknowledgement packet and $\mathrm{N_{control}}$ represent control packet count. $\mathrm{E_{idle}}$ is the node's energy expenditure in idle condition and I denote the idle period.

2.4. Progression factor

Progression factor (ρ_R) is a parameter developed to compute the node's ability to promote the data packets to the destination node at the sea surface. Progression factor is computed by the difference between the depth of sender ($\mathrm{D_m}$) and the depth of one hop nearby node ($\mathrm{D_n}$) to the maximum transmission range ($\mathrm{T_{max.range}}$) of acoustic node given by (7).

$$\rho_R = \frac{\mathrm{D_m} - \mathrm{D_n}}{\mathrm{T_{max.range}}} \quad (7)$$

Positive value of progression factor (ρ_R) indicates that the one hop neighboring acoustic sensor nodes are of lower depth than the source node and are chosen as efficient relay nodes for packet transmission. While, the negative value of progression factor (ρ_R) indicates that the acoustic relay nodes are of higher depth than the sender. The transfer of data from source to sink using ICPF based collaborative routing includes three stages associate node's information emendation phase, retention time computation and forwarding relay nodes discovery.

2.5. Associate node's information emendation phase

The acoustic nodes exchange data packets to obtain knowledge about channel attributes and archive them in its equivalent tables. At the inaugural stage, the predetermined sink sends HELLO request to its nearby associate nodes within $\mathrm{T_{max.range}}$, which inturn forwards them to its one hop associate nodes, (say $node$ m, $node$ n). Sensors can obtain the channel state and the nodes capability in forwarding the data using the parameters such as $\mathrm{P_{delay}}, \mathrm{TL}, \mathrm{SL}, \mathrm{AL}, \rho_R$. To overcome the difficulties associated with underwater channel, the proposed technique updates the associate node's information after the predetermined duration of 100s. The new parameter values are averaged with the saved parameter values as in (8)-(12).

$$\rho_{R(n)}^{\mathrm{update}} = (1-\beta) \times \rho_{R(n)}^{\mathrm{old}} + \beta \times \rho_{R(n)}^{\mathrm{new}} \quad (8)$$

$$\mathrm{P}_{\mathrm{delay}(m\to n)}^{\mathrm{update}} = (1-\beta) \times \mathrm{P}_{\mathrm{delay}(m\to n)}^{\mathrm{old}} + \beta \times \mathrm{P}_{\mathrm{delay}(m\to n)}^{\mathrm{new}} \quad (9)$$

$$\mathrm{TL}_{(m\to n)}^{\mathrm{update}} = (1-\beta) \times \mathrm{TL}_{(m\to n)}^{\mathrm{old}} + \beta \times \mathrm{TL}_{(m\to n)}^{\mathrm{new}} \quad (10)$$

$$\mathrm{SL}_{(m\to n)}^{\mathrm{update}} = (1-\beta) \times \mathrm{SL}_{(m\to n)}^{\mathrm{old}} + \beta \times \mathrm{SL}_{(m\to n)}^{\mathrm{new}} \quad (11)$$

$$\mathrm{AL}_{(m\to n)}^{\mathrm{update}} = (1-\beta) \times \mathrm{AL}_{(m\to n)}^{\mathrm{old}} + \beta \times \mathrm{AL}_{(m\to n)}^{\mathrm{new}} \quad (12)$$

The total losses encountered in the acoustic link are the summation of transmission loss, absorption loss, spreading loss calculated from (2), (4), (5). The Total Link Loss (TLL) is given by (13).

$$\text{Total Link Loss (TLL)} = \mathrm{TL}_{(m\to n)}^{\mathrm{update}} + \mathrm{SL}_{(m\to n)}^{\mathrm{update}} + \mathrm{AL}_{(m\to n)}^{\mathrm{update}} \quad (13)$$

Here, β ranges from 0 to 1 denoting the stability factor.

2.6. Retention time computation

The best relay node will continue transmitting the data towards sink while the remaining relay nodes will initialize a retention time proportional to the node's progression factor. In the inaugural phase when the sender begins its hello packet broadcasting, all the associate nodes within $T_{max.range}$ will receive them. The retention time (T_R) of the nearby node is computed from (14) from [27].

$$T_R = (1 - \rho_R)(P_{max.d}) + \frac{T_{max.range} - |\overrightarrow{D_{mRn}}|}{C} \quad (14)$$

Here, ρ_{Rn} is the Progression factor, $P_{max.d}$ represents maximum delay in propagation, C denotes speed of sound, $\overrightarrow{D_{mRn}}$ is the length amid sender (m) and relay node (n) and $T_{max.range}$ is the maximum transmission range of sensor nodes.

2.7. Forwarding relay nodes discovery

The proposed technique discovers the best forwarding relay nodes depending upon propagation delay, total link losses, residual energy and progression factor as illustrated in Figure 1. Selecting relay nodes with minimum propagation delay and link losses enhances the packet delivery rate. Thus, the acoustic channel capacity is improved. Inclusion of progression factor allows the sender to forward data efficiently therby minimizing the network delay.

Input : f,T,D,S
Output: Rbest
Direct Communication Phase
Procedure generate hello (node m)
Broadcast hello
If sink is within the coverage area of node m then
Send packet to sink
Else call ICPF based Relay Selection Phase
End if
End Procedure
ICPF based Relay Selection Phase
Procedure receive hello (node m, intermediatenode.ack)
If | depth (m)| > |depth (intermediatenode .ack)| then
Call parameters
Else drop (intermediatenode.ack)
End if
End procedure
Procedure parameters (f, T, D, S)
For each relay i=1: k
Compute P_{delay} , TLL, $E_{residual}$, ρ_R , using (1), (13), (6),(7).
End for
For each relay i=1: k
Find the relay node with minimum P_{delay} , TLL, and maximum of ρ_{Rn} and $E_{residual}$
$P_{delay} = \min[P_{delay(1)}, P_{delay(2)}, \ldots, P_{delay(k)}]$
$TLL = \min[TLL_{(1)}, TLL_{(2)}, \ldots, TLL_{(k)}]$
$E_{residual} = \max[E_{residual(1)}, E_{residual(2)} \ldots, E_{residual(k)}]$
$\rho_R = \max[\rho_{R(1)}, \rho_{R(2)}, \ldots, \rho_{R(k)}]$
If the indices of P_{delay} , TLL, $E_{residual}$ ρ_R are same
Select the corresponding index as the Best relay node
End if
End procedure

Figure 1. Algorithm for ICPF based collaborative routing

3. RESULTS AND DISCUSSION

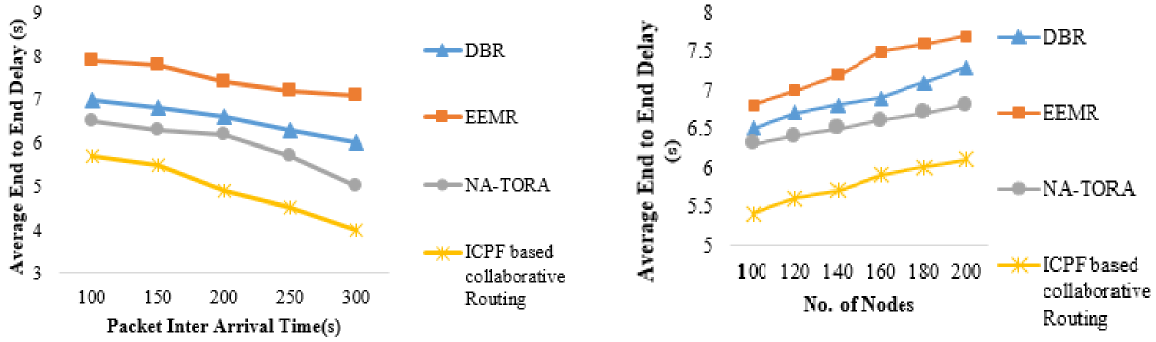
The performance of the proposed ICPF based collaborative routing is evaluated in Aquasim (NS 2.30). Acoustic nodes are randomly deployed at an area of 1100x1100x1100 m. The total number of acoustic nodes are varied from 100 to 200 and each acoustic node has a transmission range of 100 m. The parameters used to analyze the performance of the proposed ICPF based collaborative routing under the effect of varying the packet inter arrival time and node density are average end to end delay, packet delivery ratio and energy consumption. The packet inter-arrival time is defined as a time duration (in seconds) to generate a packet. Table 1 specifies the simulation parameter values.

Table 1. Simulation parameters

Parameters	Value
Simulator	Aquasim (NS2.30)
Simulation Area	1100x1100x1100m
No. of Nodes	100-200
Mobility Model	Meandering Current Mobility(MCM)
Data rate	10 kbps
Packet Inter Arrival time	50-300 s
Packet Size	200 bytes
Frequency	10 kHz
Simulation Time	700 s
Initial Energy	100 J
Speed of Sensor	0.9 m/s

3.1. Average end to end delay

Variation of average end to end delay with as shown in Figure 2. Figure 2(a) shows the performance of the proposed technique and the existing DBR [6], EEMR [9] and NA-TORA [23] techniques in terms of average end to end delay with respect to the packet inter arrival time. Initially the packet inter arrival time is set to be 100 s. It is inferred that EEMR technique has higher end to end delay because its primary focus is to minimize the energy consumption and does not have any mechanism to facilitate quick advancement of packets. But the proposed ICPF based collaborative Routing maintains minimum end to end delay because of its consideration of depth variance in the progression factor computation and inclusion of channel parameters in the forwarding relay node selection thereby enhancing the transmission of data packets towards destination. The effects in delay by varying the node count is analyzed in Figure 2(b). The collision rate in the network increases with the increase in the number of nodes leading to retransmission of packets. Though the increase in node density highly affects the ICPF based collaborative routing, it still maintains minimal delay in contrast with DBR, EEMR and NA-TORA techniques.

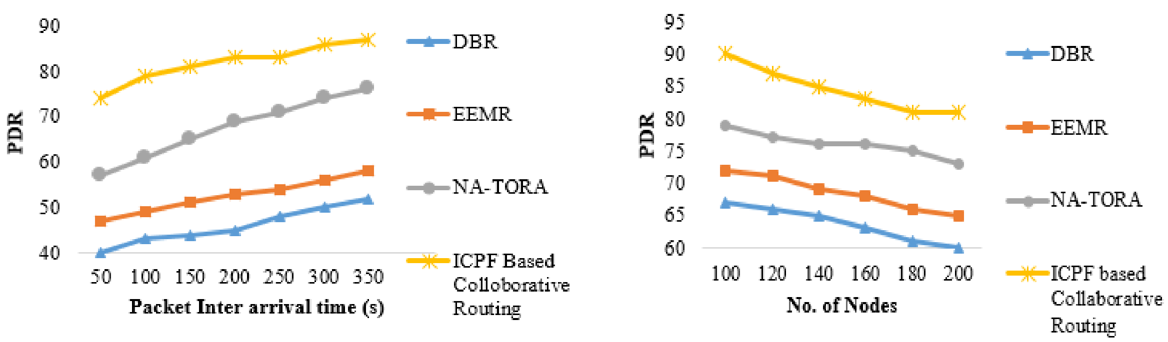


(a) (b)

Figure 2. Variation of average end to end delay with, (a) packet inter arrival time and (b) No. of nodes

3.2. Packet delivery ratio

Variation of PDR as shown in Figure 3. Figure 3(a) depicts the analysis PDR with respect to the packet inter arrival time for the proposed ICPF based collaborative Routing and existing NA-TORA, EEMR and DBR protocols. When the inter arrival time of packet is very low, the PDR decreases due to increased collision. The proposed ICPF based collaborative Routing has higher PDR when compared with respect to the existing protocols. Figure 3(b) evaluates the performance of the proposed ICPF and existing NA-TORA, EEMR and DBR protocols in terms of PDR while increasing the node density. When node count increases, the PDR decreases because of collisions incurred by simultaneous data transmissions of nearby nodes. The lack of knowledge about channel state information further increases the error which is overcome by the proposed ICPF technique. ICPF based Collaborative routing improves the PDR immensely because of its ability to receive packets efficiently.



(a) (b)

Figure 3. Variation of PDR with, (a) packet inter arrival time and (b) No. of nodes

3.3. Average energy consumption

Variation of average energy consumption with as shown in Figure 4. The assessment of the proposed ICPF based collaborative routing and the existing techniques in terms of average energy consumption by gradually increasing the packet inter arrival time from 50 to 300 s is shown in Figure 4(a). It can be seen than the average energy consumption of the DBR is higher than the EEMR, NA-TORA and the proposed ICPF based collaborative routing because it does not consider the vital energy parameter in its routing process. The proposed technique performs efficiently since it facilitates routing in dynamic channel conditions. The performance evaluation of the proposed ICPF based collaborative routing and existing protocols in terms of average energy consumption by increasing the number of nodes in the network is shown in Figure 4(b). It can be visualized that the proposed technique has lower energy consumption than the existing algorithms.

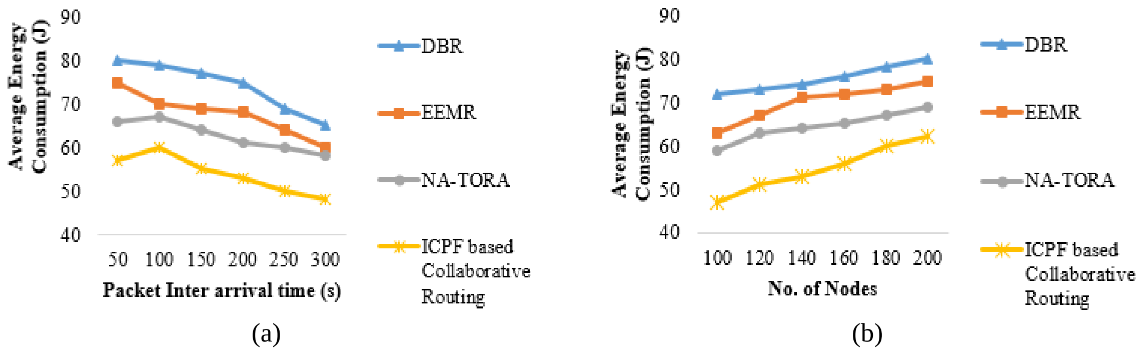


Figure 4. Variation of average energy consumption with, (a) packet inter arrival time and (b) No. of nodes

4. CONCLUSION

In this paper, an instantaneous channel characteristics and progression factor (ICPF) based collaborative routing is proposed to enhance the data transmission to the destination. It considers the computed progression factor as a prime metric to forward data efficiently thereby minimizing the end to end delay. The proposed technique comprises of three stages, namely associate node's information emendation phase, retention time computation and forwarding relay nodes discovery. The performance of the proposed technique is evaluated and analyzed with respect to the existing NA-TORA, EEMR and DBR protocols. The simulation results validate that the proposed ICPF based collaborative routing outperforms the existing schemes in terms of average end to end delay, PDR and average energy consumption.

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