A two phase energy-efficient routing protocol for underwater wireless sensor network to enhance data gathering

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Abstract: Underwater sensor network (UWSNs) characteristics such as low bandwidth, long propagation delay, limited energy, node mobility and error rate are bring many challenges in designing routing. UWSNs consist of high density sensor nodes deployed underwater to perform collaborative monitoring and resource exploration tasks over given area. The nodes in network are participates a specific task like sensing and forwarding the information to other nodes using routing protocols. Energy efficiency becomes the basic need of UWSNs in very deep water level condition and the main aim is to operate sensor with smaller battery for a longer time. In this paper, we propose an energy efficient routing protocol for UWSNs using two phase process (EERP-TP). Firstly, the balanced collective region is formed by conditional Sierpinski triangle algorithm using the node constraints, which improves the effectiveness of data gathering. Secondly, the candidate set selection is performed by chaotic multi-criteria decision (CMD) model, which computes best data forwarding node to deliver data to the destination within the required time. The simulation results show that the proposed EERP-TP method can perform very efficient than existing routing in terms of network lifetime, throughput, packet relayed rate, data loss, and energy consumption.

Keywords: two phase; collective region formation; candidate set selection; Sierpinski triangle; data gathering.

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1 Introduction

Underwater acoustic communication is a technique of sending and receiving message below water. There are several ways of employing such communication but the most common is using hydrophones (Vieira et al., 2010). Under water communication is difficult due to factors like multi-path propagation, time variations of the channel, small available bandwidth and strong signal attenuation, especially over long ranges (Benson et al., 2010). In underwater communication, there are low data rates compared to terrestrial communication, since underwater communication uses acoustic waves instead of electromagnetic waves (Abdi and Guo, 2009). By providing nodes with underwater wireless communication capabilities, underwater sensor networks (UWSNs) enable real-time monitoring and actuation, online system reconfiguration, and failure detection (Pompili et al., 2009). This technology has enabled a new era in scientific and industrial underwater monitoring applications, such as ocean exploration, oceanographic data collection, ocean and offshore sampling, navigation assistance, and tactical surveillance applications (Headrick and Freitag, 2009).

Vector-based forwarding (VBF) (Huang et al., 2011) protocol is oldest one used to provide robust, scalable and energy efficient routing, based on a location-based routing approach. No state information is required on the sensor nodes and only a small fraction of the nodes are involved in routing. Packets are forwarded in redundant and interleaved paths, which add robustness to VBF. Energy optimised path unaware layered routing protocol (E-PULRP) for dense 3D UWSN (Zhou et al., 2012) sensor nodes report events to a stationary sink node using on the fly routing. E-PULRP consists of a layering phase and communication phase. A layering structure (Zhou and Cui, 2008) presented wherein nodes occupy different layers in the form of concentric shells, around a sink node. The reverse localisation scheme (RLS) (Guo et al., 2008) based an event-driven localisation method triggered by detector sensors for launching localisation process. RLS is suitable for surveillance applications that require very fast reactions to events and could report the location of the occurrence. Mobile sensor nodes report the event toward the surface anchors as soon as they detect it. A range-free localisation with a mobile beacon (LoMoB) (Xiujuan, 2012) is one of the most important issues associated with underwater acoustic sensor networks, especially when sensor nodes are randomly deployed. But, the continuous challenges in UWSNs of obtaining full-dimensional location information of sensor nodes through localisation process, depth-based routing called drum buffer rope (DBR) protocol (Johnson and Maltz, 1996). The lower layers of the communication stack, and envision future trends and challenges; UWSN analyzes the current state-of-the-art on the physical, medium access control and routing layers.

In opportunistic routing (OR) (Noh et al., 2016) which has been completely investigated in global wireless ad hoc network plot, has greater potential for alleviating drawbacks from underwater acoustic communication and improving network performance. A potential group of nodes are selected to help as the next-hop forwarder. Each candidate that receives the packet can continue forwarding the packet. Underwater opportunistic routing (UWOR) (Hsu et al., 2015) maximises the data good-put while satisfying end-to-end latency requirements of delay-sensitive applications in UWSNs. The delay sensitive characteristics achieve by using a two-step heuristic algorithm composed of per-node forwarding set determination and packet forwarding prioritisation. A method for cluster-based forwarding set selection (Chen et al., 2014) that builds up possible forwarding sets around each neighbour of the node in network. This includes an iterative call to the aforementioned prioritisation scheme (Yan et al., 2008) to maintain the proper internal priority order during the progressive build-up of each cluster. A seismic monitoring system (Mohapatra et al., 2013) using the wireless acoustic transmission for transferring data, and the deployment period of such networks extends well beyond the battery lifetimes of the nodes. A link state-based adaptive feedback protocol (Zhang et al., 2013) use the link state information from symmetrical or asymmetric link, and an adaptive routing feedback method is adopted to make full use of the underwater asymmetric link and save energy. A void-aware pressure routing (VAPR) protocol (Noh et al., 2013) using the sequence number, hop count and depth information embedded in periodic beacons to set up next hop direction and to build a directional trail to the closest neighbours. Level-based adaptive geo-routing (LB-AGR) protocol (Du et al., 2014) divides traffics into four categories, and routes different types of traffic in accordance with different decisions. Channel-aware routing protocol (CARP) (Basagni et al., 2015) avoids the loops and can successfully route around connectivity voids and shadow zones by using simple topology information, such as hop count.

1.1 Our contributions

An energy efficient routing protocol is proposed for UWSNs using two phase process (EERP-TP) are collective region formation and candidate set selection. The main objective of EERP-TP method can effectively overcome the energy consumption problem without affecting other metrics such as reduced delay time, and maximise the network lifetime. The rest of this paper is organised as follows. Section 2 provides the review of recent works related to our contributions. In Section 3, we provide the problem methodology and network model of EERP-TP. In Section 4, we present the detailed description of proposed protocol with algorithm steps. The performance evaluation of the proposed protocol is given in Section 5. Finally, the paper concludes in Section 6.

2 Related works

Jiang et al. (2016) have presented the geographic routing using unique characteristics of underwater environment such as the three dimensional topology, the limited bandwidth and power resources. The three dimensional underwater network is first divided into small cube spaces, thus data packets are supposed to be collaboratively transmitted by unit of small cubes logically. The complex properties of underwater medium divided into three dimensional topologies such as high propagation delay and path loss of acoustic channel, two multi-path strategies called greedy geographic forwarding based on geospatial division (GGFGD) and geographic forwarding based on geospatial division (GFGD) used to reduced the challenges and the energy consumption is also reduced, but the data gathering problem introduced in this channel.

Coutinho et al. (2016) have proposed a combined technique called GEDAR routing protocol which overcome the limitation of acoustic channel communication characteristics. To improve the data collection in UWSNs is through the design of routing protocols considering the unique characteristics of the underwater acoustic communication and the highly dynamic network topology. GEDAR is any cast, geographic and OR protocol that routes data packets from sensor nodes to multiple sinks. When the node is in a communication void region, GEDAR switches to the recovery mode procedure which is based on topology control through the depth adjustment of the void nodes, instead of the traditional approaches using control messages to discover and maintain routing paths along void regions.

Noh et al. (2016) have designed an efficient any cast routing algorithm for reliable underwater sensor event reporting to any surface sonobuoy. They consider major challenges are bandwidth and energy that is addressed by hydro cast manner. A hydraulic pressure-based any cast routing protocol that exploits the measured pressure levels to route data to the surface sonobuoys. An OR mechanism used to select the subset of forwarders that maximise the greedy progress yet limits co-channel interference and efficient underwater dead end recovery method.

(Zhou, et al., 2016) have proposed an enhanced version of the channel-aware routing protocol (E-CARP), which achieves the location-free and greedy hop-by-hop packet forwarding strategy. Generally, CARP does not consider the reusability of previously collected sensory data to support certain domain applications afterwards, which induces data packets forwarding which may not be beneficial to applications. The PING-PONG strategy used to select the most appropriate relay node at each time point, when the network topology is relatively steady.

Noh et al. (2013) have proposed a hydraulic pressure-based any cast routing that allows time critical sensor at sea level using acoustic multi-hopping. This routing protocol with salient features of novel OR mechanisms to select the subset of forwarders that maximises the greedy progress yet limits the co-channel interference. It is also an efficient underwater dead end recovery method. The acoustic transmissions are power hungry, the goal achieved by minimises the number of packet transmissions in underwater sensor deployments that are challenged by ocean currents, unreliable acoustic channels, and voids.

Li et al. (2016) have proposed a depth-based routing aware MAC protocol (DBR-MAC), which improves the throughput, energy and time efficiency at the cost of fairness. A depth-based transmission scheduling scheme is introduced based on the depth information, angle information and overheard one-hop neighbouring nodes' transmissions to make key nodes have higher priority to access the channel than other nodes. DBR-MAC is a cross-layer scheme and its' directional forwarding tries best to forward packets from source to the floating sink node by the least hops.

Rahman et al. (2017) have proposed energy-efficient cooperative opportunistic routing (EECOR) protocol for forward the packets towards the surface sink. Here, a forwarding relay set is computed by the source node based on the local information of the forwarder and then, a fuzzy logic-based relay selection (FLRS) scheme applied to select the best relay based on considering the energy consumption ratio and the packet delivery probability of the forwarder. The packet collisions problem is alleviated by a timing setup like holding timer for each of the forwarder to schedule the packets transmission towards the surface sink.

Rani et al. (2017) have proposed an energy efficient chain-based routing protocol (E-CBCCP). While keeping in view the complex features of underwater dynamics, dynamic network topology and node mobility, energy of the cluster heads (CHs), relay nodes (RNs) and cluster coordinators (CCOs) has been considered during the transmission of data and role of the CHs, CCOs and RNs changed after some time. Distance-based communication is based on the location aware nodes and can be used in monitoring domains during steady state but in dynamic state, location free communication is required therefore RN communication is based on hop to hop.

Han et al. (2017) have proposed an asymmetric link-based reverse routing (AREP) based on table-driven routing protocol. Link state information is obtained during neighbour table establishment. AREP prioritises the use of symmetric links to establish routing paths. When an asymmetric link is added in the path, a circuitous route is established for ease of reverse routing search. AREP also addresses the routing void problem caused by a greedy forwarding strategy. The influence of node mobility is relieved during the routing update phase

Kanthimathi (2017) have proposed void handling using geo-opportunistic routing (VHGOR) protocol based on GOR routing to forward packets to the sink through multi-hop. VHGOR is a simple scalable geo-OR protocol that gathers knowledge from the location of the nodes and takes advantage of the broadcast communication medium to greedily forward data packets towards the surface of the sea. This protocol has salient features like convex hull formation, neighbour beaconing based on OR-based distance progress (ORDP) metric, forwarding candidate set prioritisation through expected packet progress (EPP) and identifying void through convex and concave void handling methods that maximise the greedy process to deliver packets to the sink.

3 Problem methodology and system model

3.1 Problem methodology

Cheng and Li (2017) have addressed the problem of how to identify the importance level of data without domain knowledge and set a delay time requirement for data according to their important levels. Then, collect sensing data using an approach that integrates data gathering by multi-hop transmission, i.e., called data gathering algorithm for sensors (DGS). This method allowed to solving the problem of unbalanced energy consumption and the problem of long delay time of important data. This method determines the importance level of data without domain knowledge with the normal distribution offers a rule of thumb; and the network stratification mechanism used to perform the collection region. The layer swap mechanism used to effectively solve the long delay time and the unbalanced energy consumption problems to further extend the network lifetime. UWSNs are mainly used for responsible real-time applications such as environmental monitoring, undersea explorations, disaster prevention, navigation assists, tactical surveillance and mine reconnaissance. In general, the unique features like high latency, limited bandwidth, multi-channel fading and high error probability make the UWSNs significantly different from terrestrial WSNs. The battery power is a major issue for UWSN because of the high cost of deploying and re-deploying underwater equipment. From recent works (Jiang et al., 2016; Coutinho et al., 2016; Noh et al., 2016, 2013; Zhou et al., 2016; Li et al., 2016; Rahman et al., 2017; Rani et al., 2017; Han et al., 2017; Kanthimathi, 2017; Cheng and Li, 2017), we have the following issues that have to be addressed with proper methods. The main issue is energy efficiency which is more difficult in UWSNs from the WSNs for node deployment and repair process. Due to deployment, mobility and resource limitation, the network is not easy to provide the path for data forwarding. These problems are affects the data gathering process in UWSNs. Moreover, sensor node-based data gathering (Cheng and Li, 2017) must need external device or buffered memory for store the gathered data's.

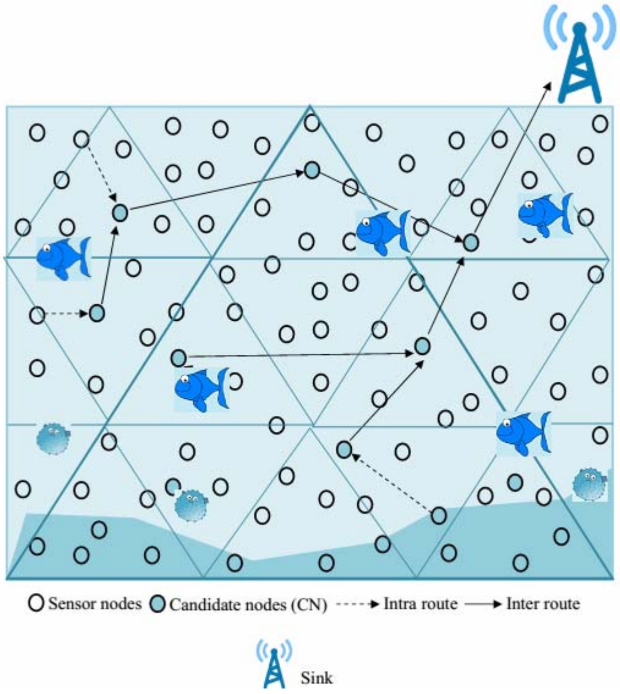
A number of problems confront us in achieving this goal. These problems are overcome by the two phase energy efficient routing protocol (EERP-TP), which improve energy efficiency to enhance the data gathering process. In first phase, the balanced collective region is formed by the conditional Sierpinski triangle algorithm, which reduces the unbalanced collective region to make energy efficient and maximise the data gathering. The algorithm is inspired from the Sierpinski triangle (Guiloufi et al., 2015)which used to control the cluster size to make an unequal clustering in WSNs. In second phase, compute candidate node (CN) using a chaotic multi-criteria decision (CMD) model from node constraints such as energy consumption, network lifetime, good put, and mobility. The selected CN are able to forward the data from source node to other nodes in the network within the required time. The main contributions of proposed work are summarised as follows:

- In EERP-TP, the conditional Sierpinski triangle algorithm used to form unbalanced collective region, which reduce the energy consumption to make efficient data gathering
- A CMD model used to select CN among multiple nodes and it used to forward data from source to other nodes in acoustic environment.
- Finally, a set of simulations were designed, implemented and executed to evaluate the effectiveness of EERP-TP, by varying sensor node density and data rate, and comparing the proposed protocol with DGS method (Cheng, and Li, 2017).

3.2 System model of proposed EERP-TP method

The system model of proposed EERP-TP method consists of high density sensor nodes at the bottom of the ocean. Autonomous underwater vehicles (AUV) are interconnected to each other by one or more underwater sinks using wireless acoustic links. Underwater sensor nodes are equipped with a limited battery and stay at a certain depth with high densities in the target field, all the sensor nodes will use the proposed algorithm to gather the sensing data. The example of UWSN with collective region is illustrates in Figure 1.

Figure 1 System model of proposed EERP-TP method (see online version for colours)



4 Proposed EERP-TP

In this section, the detailed description of proposed clustering and control OH message reduction techniques are presented as follows.

4.1 Collective region formation using conditional Sierpinski triangle algorithm

The Sierpinski triangle is constructed as a mathematical curve, this is one of the basic examples of self-similar sets and it is a mathematically generated pattern that can be reproduced at any magnification or reduction. An algorithm for obtaining arbitrarily close approximations to the Sierpinski triangle is as follows:

1. Start with an equilateral triangle with a base parallel to the horizontal axis.
2. Shrink the triangle by 1/2, make two copies, and position the three shrunk triangles so that each triangle touches each of the two other triangles at a corner.
3. Repeat step 2 with each of the smaller triangles.

In most solutions, graph nodes and edges are typed and carry information important for the generation process. Some solutions also use additional nodes or edges to store data about intermediate steps of the Sierpinski triangle generation (Guiloufi et al., 2015). Moreover, also node attributes are used for storing additional information. Clearly, additional graph elements and attributes may affect the efficiency of graph representation. All solutions contain one or more rules for performing an elementary Sierpinski step. All generation steps, except the first one, consist of several applications of the elementary step. The solutions show different kinds of controlling rule applications. The generation of Sierpinski triangles is well suited for parallel rule application and means that the basic Sierpinski step is performed on all triangles being ‘alive’ simultaneously. Sequential rule application necessarily leads to intermediate graphs where some atomic triangles of the current generation step are already refined, while others still have to be considered. For not refining an already refined triangle again in the same generation step, some application control has to be added which can be done in different ways. Some solutions add further graph elements holding information about the generation process and/or add application conditions to their generation rules or even add further rules, while others rely on external control which is formulated by, e.g., regular expressions. Besides just controlling the selection of rules, some solutions even control the rule matching explicitly and thus eliminate any kind of non-determinism in rule application.

Consider a number of particles (sensor nodes) are randomly set into motion through the space and observe the fitness value of own and their neighbours and emulate successful neighbours by moving towards them. The particles are computed by different schemes, semi independent flocks are used or all the particles can belong to a single global flock. The collective region phase is start with a group of random particles and then searches for optimal by updating generations, each particle is updated by following two best values. The first best solution represents as P_{best}, another best value is global best, i.e., g_{best} is tracked and obtained so far by any particle in the population.

$$p_{best_k} = \begin{cases} p_k, & \text{if } \left(\text{fitness}\left(p_k\right) < \text{fitness}\left(p_{best_k^i}\right)\right) \\ p_{best_k} & \text{otherwise} \end{cases} \tag{1}$$

$$g_{best_k} = \begin{cases} p_k, & \text{if } \left(\text{fitness}\left(p_k\right) < \text{fitness}\left(g_{best_k^i}\right)\right) \\ g_{best_k} & \text{otherwise} \end{cases} \tag{2}$$

A particle takes part of the population as its topological neighbours and the best value is a local best and is called I_{best}. In mathematically, the particles are initialised randomly over the search space and move through dimensional space to determine new solution. The position P_K^i and velocity V_K^i of i^{th} particle at the k^{th} iteration, then its velocity and position of this particle at $(K + 1)^{\text{th}}$ iteration are updated as follows:

$$\begin{aligned} V_{k+1}^i &= \omega.V_k^i + c_1.rand_1\left(p_{best_k^i} - P_k^i\right) \\ &\quad + c_2.rand_2.\left(g_{best_k} - P_k^i\right) \end{aligned} \tag{3}$$

$$P_{k+1}^i = P_K^i + V_{k+1}^i \tag{4}$$

where ω is inertia weight, constant C_1, C_2 representing the learning factors normally equal to 2, and $rand_1$ and $rand_2$ represents random numbers between 0 and 1.

4.2 Candidate node selection using CMD model

After collective region formation, BS collects design constraints from every node such as energy consumption, end-to-end delay, mobility, and cooperation for CN selection process. The energy consumption of sensor node is modelled by different operation regions such as sensing, processing and wireless communication.

The energy consumption of sensing region (E_S) defined as

$$E_S = E_{off-on} + E_{on-off} + \left(E_s\right) \tag{5}$$

where $E_{off\text{-}on}$ is the switching energy consumption from the OFF to ON state, $E_{on\text{-}off}$ is the switching energy consumption from the ON to OFF state and E_s is the energy consumption of the sensing operation. The energy consumption due to sensing region as

$$E_s = E_\eta + E_{AD} + E_\varphi \tag{6}$$

where E_η represents the energy consumption due to signal sampling, E_{AD} denotes the energy consumption due to the analogue to digital conversion and E_m is the energy consumption due to modulation of the signal. The energy consumption of data processing region (E_S) defined as,

$$E_P = E_o + E_\vartheta \tag{7}$$

Where E_o represents the state energy consumption and E_ϑ represents the state transition energy consumption. The detailed description as follows:

$$E_P = \sum_{i=1}^{m} \sum_{j=1}^{n} P_o(i)T_o(i) + F_\vartheta(j)t_\vartheta(j) \tag{8}$$

where $P_o(i)$ denotes the power consumption cost, $T_o(i)$ denotes the time interval, $F_\vartheta(j)$ represents the frequency of the state transition, and $t_\vartheta(j)$ denotes the energy consumption cost of a single state transition. When message is either transmitted or received over a measured distance d, then the energy expense is formulated as follows,

$$E_{T/R}(l, d) = \begin{cases} l\left(E_{elec} + \varepsilon_0 d^2\right) & d < d_0 \\ l\left(E_{elec} + \varepsilon_1 d^4\right) & d \geq d_0 \end{cases} \tag{9}$$

where ε_0 and ε_1 are the radio amplifier types that depend on type of condition met and d_0 represents the reference distance is $d_0 = \sqrt{\varepsilon_0 / \varepsilon_1}$. Finally, total energy consumption as follows

$$E_{total} = E_S + E_P + E_C \tag{10}$$

The delay of vehicle node computed from the collective region equivalent model with an average intra collective region distance (d_{intra}) is defined as the average of the sum of the distances of all the sensor nodes from their selected candidate node (x).

$$d_{\text{int}ra} = \frac{1}{I_x} \sum_{y=1}^{I_y} dis\left(V_y, x\right) \tag{11}$$

Average BS distance (d_{BS}) is defined as the ratio of distance between a candidate node (x) and the BS through intermediate candidate nodes.

$$d_{BS} = \frac{1}{I_x} dis(x, BS) \tag{12}$$

In intra cluster and routing phase, all vehicles consume some energy to send data to their CH and it is required to route their aggregated data to the BS. In order to consume less energy, we need to reduce this average intra-collective region communication distance in intra collective region communication and select candidate node. The total delay consumption is represents as follows:

$$D_{total} = \sum_{x=1}^{m} \left(d_{\text{int}ra} + d_{BS}\right) \tag{13}$$

Mobility is the distance and relative speed determine the speed accurately according to the current sampled signal strength, sample points are selected which meet constrain $\Delta t_1 = \Delta t_2 = \Delta t$, but the sample domain may have no such points. Different reference points are used to approximate nodes' actual received signal strength. The relative speed of sensor nodes compute form the example with the consideration of D_{i_1}, D_{i_2} and D_{i_3} can be obtained and modified distance is computed from the cosines laws as follows:

$$D_{i_1}^2 = D_{i_2}^2 + a_1 a_2^2 - 2D_{i_2} \cdot a_1 a_2 \cdot \cos(\alpha) \tag{14}$$

$$D_{i_3}^2 = D_{i_3}^2 + a_1 a_2^2 - 2D_{i_2} \cdot a_1 a_2 \cdot \cos(\beta) \tag{15}$$

The current position of node a is and can move a_1 to a_2 and in two reference points respectively. Consider $\cos(\alpha) = -\cos(\beta)$ and simply above equation to compute velocity (v) as follows:

$$2a_1 a_2^2 = D_{i_1}^2 + D_{i_2}^2 - 2D_{i_3}^2 \tag{16}$$

$$v = \sqrt{\frac{2\left(D_{i_1}^2 + D_{i_2}^2 - 2D_{i_3}^2\right)}{2\Delta t}} \tag{17}$$

The movement duration for sensor node from current position a to the moved position a_1 or a_2 is expressed as the distance $T_{a,a_1/a_2}$ divided the node's velocity and it can obtain by sign law as follows:

$$T_{a,a_1/a_2} = \frac{R \cdot \sin\vartheta}{\sin\beta \cdot v} \tag{18}$$

Applied formulation (14) in to (18) and we got,

$$M = T_{a,a_1/a_2} = \frac{\Delta t \cdot R \cdot \sin\vartheta}{\sin\beta \cdot \sqrt{\frac{\left(D_{i_1}^2 + D_{i_2}^2 - 2D_{i_3}^2\right)}{2}}} \tag{19}$$

The cooperation rate of node defines the correlation between node and BS. The cooperation rate at time between time t, is gotten the hang of utilising a weighted customary of the attestation rating factors gave by focus fixations having a place with the neighbours set of the middle. The condition used to compute the cooperation rate of node (x) at time interim (t).

$$C(x, t, F) = \int_{i=0}^{n} d\left(x_i(t), BS(t)\right) + CR_i \tag{20}$$

The congestion rate (CR) is used to evaluate the load of node. Here, the each intermediate node is able to adaptively detect the occurrence of congestion and then notify the parent nodes to reduce the packet delivery rate according to the congestion level. The bare rate of each node is calculated as follows:

$$CR = v_i = \frac{\sum_{i=1}^{N} PI\left(P_i\right) - PI\left(P_i\right)}{\sum_{i=1}^{N} PI\left(P_i\right)} \tag{21}$$

where the bare rate of the node i is v_i and $V = \{v_i, 1 \leq i \leq m\}$; $PI(P_i)$ is the node importance index, which computes a quantitative indicator. It can be defined as

$$PI\left(P_i\right) = \sum_{n_i \in L_{ij}^m} C\left(n_i\right) \tag{22}$$

where $C(n_i)$ represents the connectivity degree describes how close the node is to neighbours. Here, we use a coverage probability to represent the connectivity degree. It can be obtained by

$$C(n_i) = \left|\sigma_{ij}(n_k)\right| \tag{23}$$

where $\sigma_{ij}(n_k)$ represents the edge number from n_i to n_k on node L_{ij}.

The four constraints are time varying factors, here, we consider as optimal problem. The problem is overcome by proposed multi-criteria decision CMD model. The CMD model perform inside in the water is, random behaviour-in general, fish looks at random for food and other companion; searching behaviour when the CMD model discovers a region with more food, it will go directly and quickly to that region; swarming behaviour when swimming, CMD model will swarm naturally in order to avoid danger; chasing behaviour when a CMD model in the swarm discovers food, the others will find the food dangling after it; and leaping behaviour, when CMD model stagnates, a leap is required to look for food in other regions. The proposed modification is done by the extension to maintain inside the bounds along with the iterative process in random, searching and leaping CMD model behaviours. The proposed CMD model starts with the initialisation process. The initial population of m point is randomly generated in the set (S). Each point x_i in the population is computed as follows:

$$x_i^t \leftarrow n_t + \delta(m_t - n_t); \qquad t = 1, 2, \ldots, n \tag{24}$$

where δ is assumed to be uniformly distributed between 0 and 1, m_t and n_t denotes the upper and lower constraints of initial stage. The best and worst function values are compute as follows:

$$f_b = \min\{f(x_i); \quad i = 1, 2, \ldots, n\} \tag{25}$$

$$f_w = \max\{f(x_i); \quad i = 1, 2, \ldots, n\} \tag{26}$$

A fixed visual value for all the population depends on the bound constraints of the problem which will define by designer.

$$V = \max_{t \in \{1,\ldots,n\}} (m_t - n_t) \tag{27}$$

when V is empty means point of population moves randomly, otherwise select point as random manner which is better than x_i. The swarming, chasing and searching behaviours can be seen as local behaviours. When V is not empty, the algorithm activates the searching behaviour and randomly selects a point inside the visual scope, i.e., an index is randomly selected and the point x_i is moved towards if the condition $f(x_r) < f(x_i)$ holds. The direction of movement is denotes as follows:

$$\text{direction}_i = x_r - x_i \tag{28}$$

Thus, the direction of movement is used to compute the new point position is called the trial point t_i, it is called swarming behaviour. In chasing, considers a movement towards the point that has the least function value, herein denoted by $x_{\min}$. The direction used to compute the new trial point as follows:

$$\text{direction}_i = x_{\min} - x_i \tag{29}$$

The movement towards any particular point, i.e., along any particular direction, is carried out component by component and takes into account the allowed movement towards the upper and lower bound in the set. The newly generated trail points t_i are select for next levels is depends on the condition as,

$$x_i = \begin{cases} t_i; & \text{if } f(t_r) < f(x_i) \\ x_i; & \text{otherwise} \end{cases} \tag{30}$$

After optimise the time varying constraints of sensor node compute own strength (V_s) as follows:

$$V_s = x_1 + x_2 + x_3 + x_4 \tag{31}$$

where x_1 presents the E_{total}, x_2 represents the D_{total}, x_3 represents the C and x_4 represents the CR. Then, CN is computed as follows:

$$CN_i = \max\left(V_s^1, V_s^2, V_s^3, \cdots V_s^n\right) \tag{32}$$

5 Simulation result

In this section, we evaluate the performance of proposed EERP-TP and it is compared with existing data gathering algorithm for sensors DGA (Cheng and Li, 2017).

5.1 Simulation parameters

The proposed EERP-TP algorithm is simulated by the network simulator (NS-2) tool with the sensor nodes move in a 2,000 m × 2,000 m square region for 1800 seconds simulation time. The channel capacity of mobile hosts is set to the value of 2 Mbps. The simulated traffic source is constant bit rate (CBR). The sensor node mobility model is random way model. The overall monitoring radius is 100 units distance, monitoring depth is 500 units distance. All sensor nodes have the same transmission range of 40 units distance. The initial energy of a sensor node is 104 W. The energy cost to transmit one unit of data is 10 W and receive one unit of data is 3 W. The performance of proposed EERP-TP routing protocol is analyzed by two different testing scenarios is impact of node density and packet size. The simulation parameters are summarised in Table 1.

Table 1 Simulation parameters

Parameters	*Values*
Number of nodes	600–1,000 (variable)
Packet size (bytes)	128–1,538 (variable)
Node mobility	10 m/s
Mobility model	Random way point
Simulation area	2,000 m × 2,000 m
Initial energy of a sensor	104 W
Traffic source	CBR
Simulation time	1800 s

The performance of our proposed EERP-TP algorithm is compared with the existing protocol DGA (Cheng and Li, 2017) in terms of delay, improvement ratio, energy consumption, network lifetime and throughput. Delay is the average time, in seconds taken for a data packet to travel from the source to destination. The improved ratio is the ratio of number of packets received successfully and the total number of packets transmitted. Energy consumption is the amount of energy consumed by the nodes for the data transmission. Network lifetime is the time during which the network is operational. In other words, the lifetime of network is defined as the operational time of the network during which it is able to perform the dedicated task(s). Throughput is the amount of packets moved successfully from one place to another in a given time period.

5.2 *Impact of node density*

In this experiment, we compute performance metrics with fixed network size as 2,000 × 2,000 m^2 area. We varying the number of nodes as 600, 700, 800, 900 and 1,000 with the average speed is 10 m/s. The simulation time of this test is set as 1,800 seconds and compute performance metrics.

Figure 2 shows the delay for both two protocols when node density is increased. The plot clearly depicts the delay of the proposed EERP-TP protocol is better than existing DGA for different number of sensors operating in the network topology. Figure 3 shows the improvement ratio for both two protocols when node density is increased. The plot clearly depicts the improvement ratio of the proposed EERP-TP protocol is better than existing DGA for different number of sensors operating in the network topology. Figure 4 shows the energy consumption for both two protocols when node density is increased. The plot clearly depicts the energy consumption of the proposed EERP-TP protocol is better than existing DGA for different number of sensors operating in the network topology. Figure 5 shows the network lifetime for both two protocols when node density is increased. The plot clearly depicts the network lifetime of the proposed EERP-TP protocol is better than existing DGA for different number of sensors operating in the network topology. Figure 6 shows the throughput for both two protocols when node density is increased. The plot clearly depicts the throughput of the proposed EERP-TP protocol is better than existing DGA for different number of sensors operating in the network topology.

Figure 2 Performance comparison on delay with node density (see online version for colours)

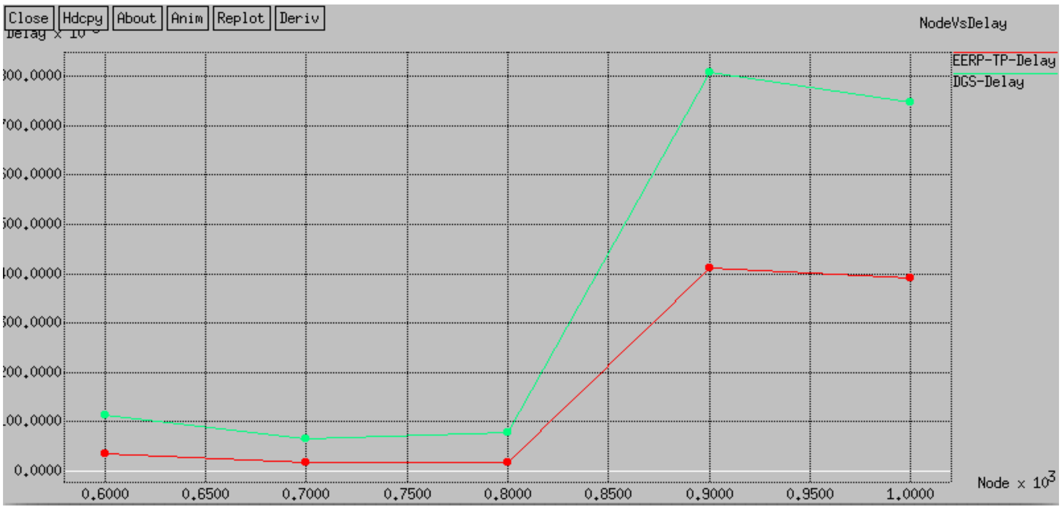


Figure 3 Performance comparison on improved ration with node density (see online version for colours)

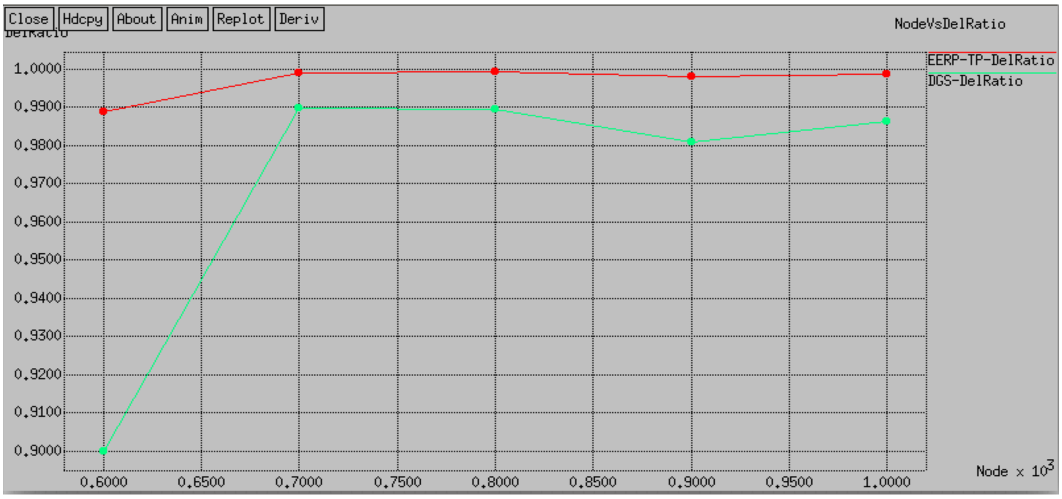


Figure 4 Performance comparison on energy consumption with node density (see online version for colours)

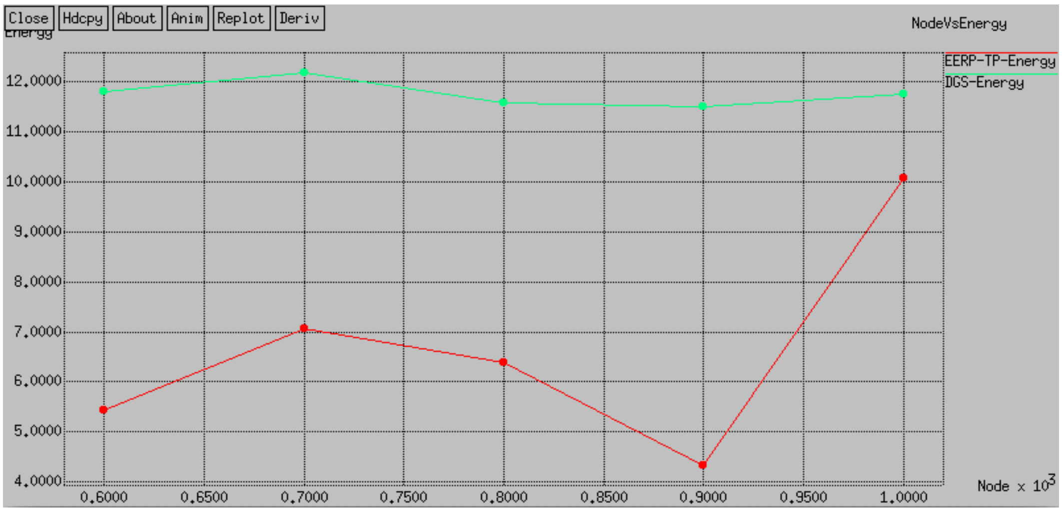


Figure 5 Performance comparison on network lifetime with node density (see online version for colours)

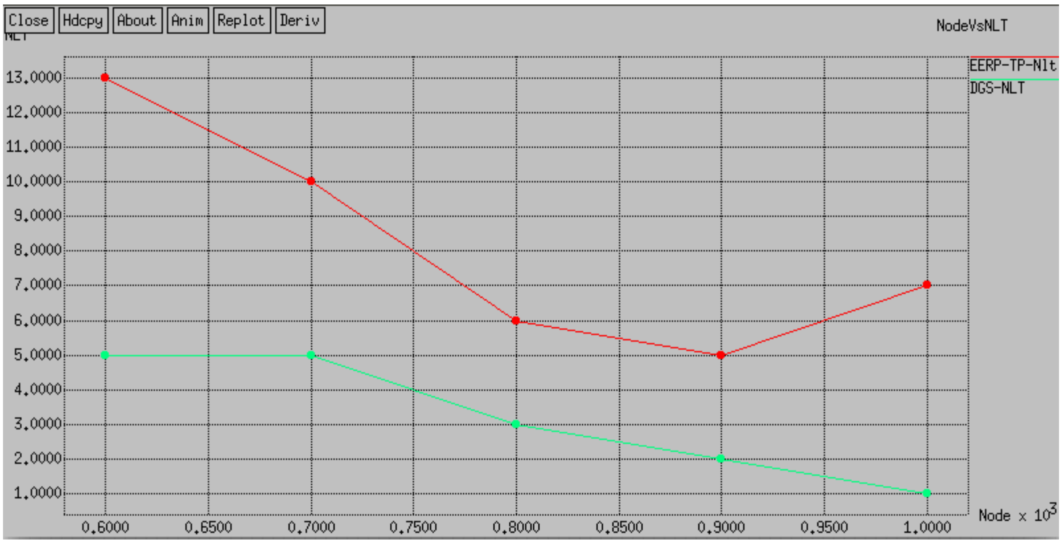


Figure 6 Performance comparison on throughput with node density (see online version for colours)

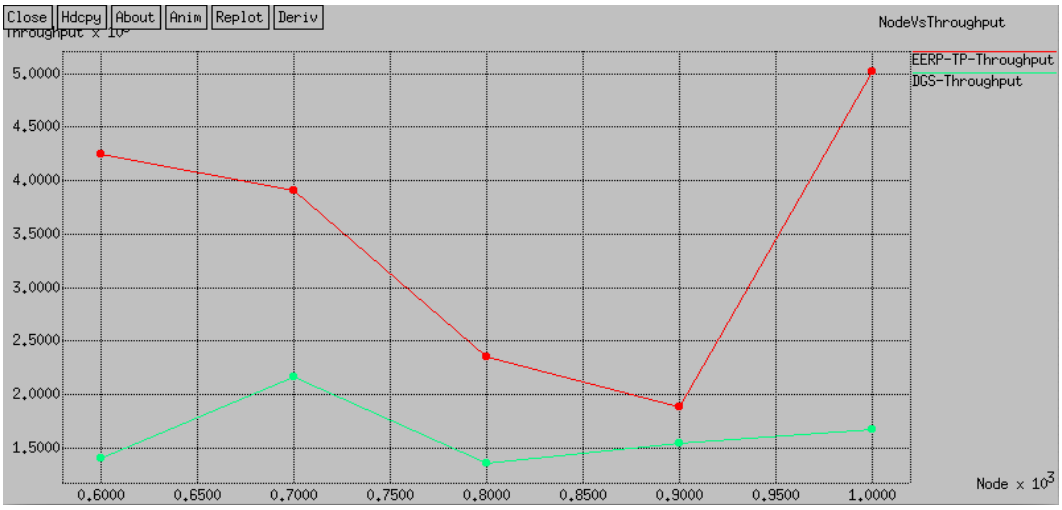


Figure 7 Performance comparison on delay with different packet size (see online version for colours)

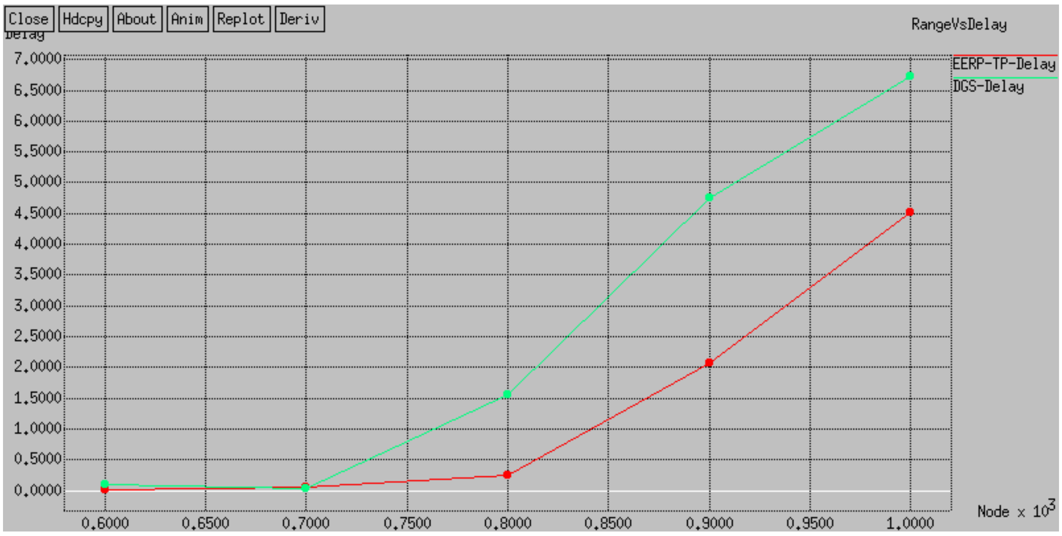


Figure 8 Performance comparison on improved ration with different packet size (see online version for colours)

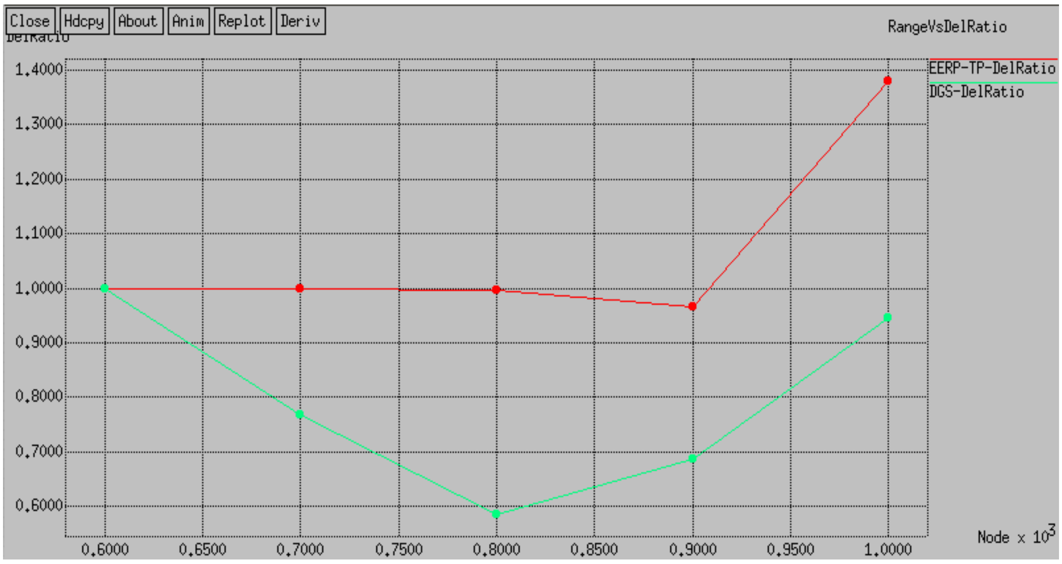
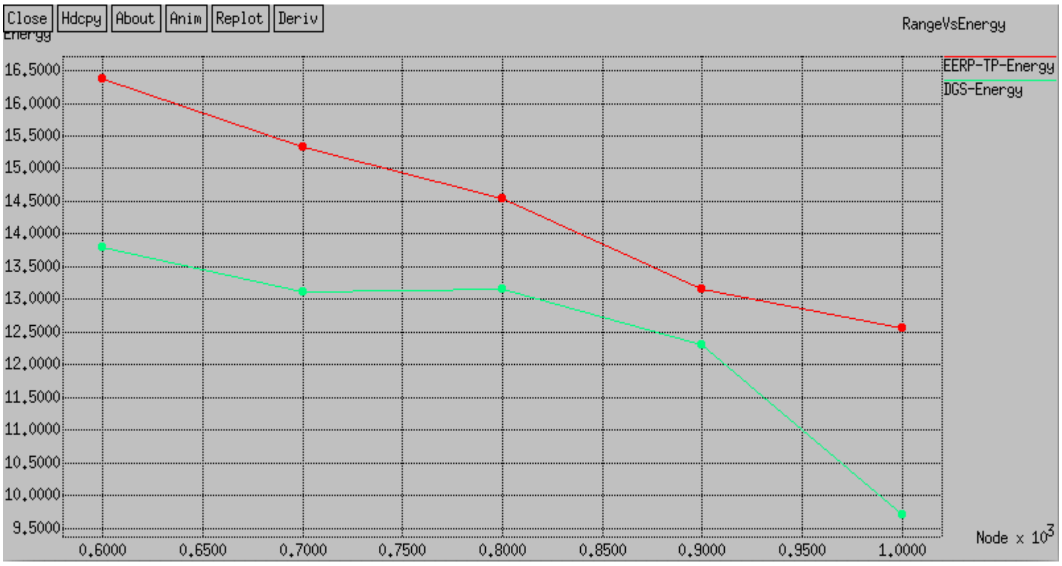


Figure 9 Performance comparison on energy consumption with different packet size (see online version for colours)



5.3 *Impact of packet size*

In this experiment, we compute performance metrics with fixed network size as 2,000 m^2 × 2,000 m^2 area with fixed number node as 800. We varying the packet size as 128, 256, 512, 768, 1,024 and 1,536 with the average speed are 10 m/s. The simulation time of this test is set as 1,800 seconds and compute performance metrics.

Figure 7 shows the delay for both two protocols when node density is increased. The plot clearly depicts the delay of the proposed EERP-TP protocol is better than existing DGA for different packet size. Figure 8 shows the improvement ratio for both two protocols when node density is increased. The plot clearly depicts the improvement ratio of the proposed EERP-TP protocol is better than existing DGA for different packet size. Figure 9 shows the energy consumption for both two protocols when node density is increased. The plot clearly depicts the energy consumption of the proposed EERP-TP protocol is better than existing DGA for different packet size. Figure 10 shows the network lifetime for both two protocols when node density is increased. The plot clearly depicts the network lifetime of the proposed EERP-TP protocol is better than existing DGA for different packet size. Figure 11 shows the throughput for both two protocols when node density is increased. The plot clearly depicts the throughput of the proposed EERP-TP protocol is better than existing DGA for different packet size.

Figure 10 Performance comparison on network lifetime with different packet size (see online version for colours)

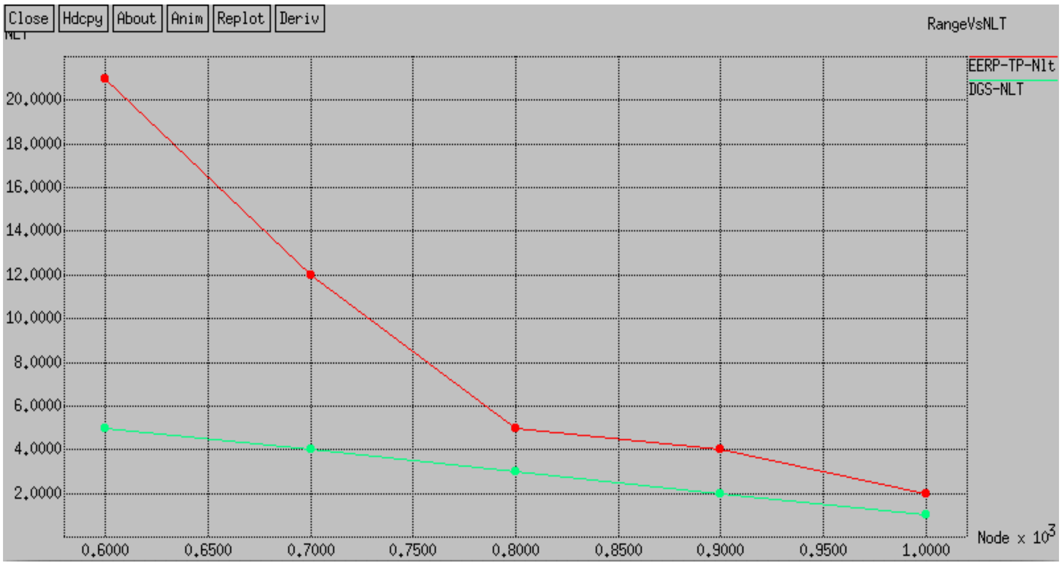
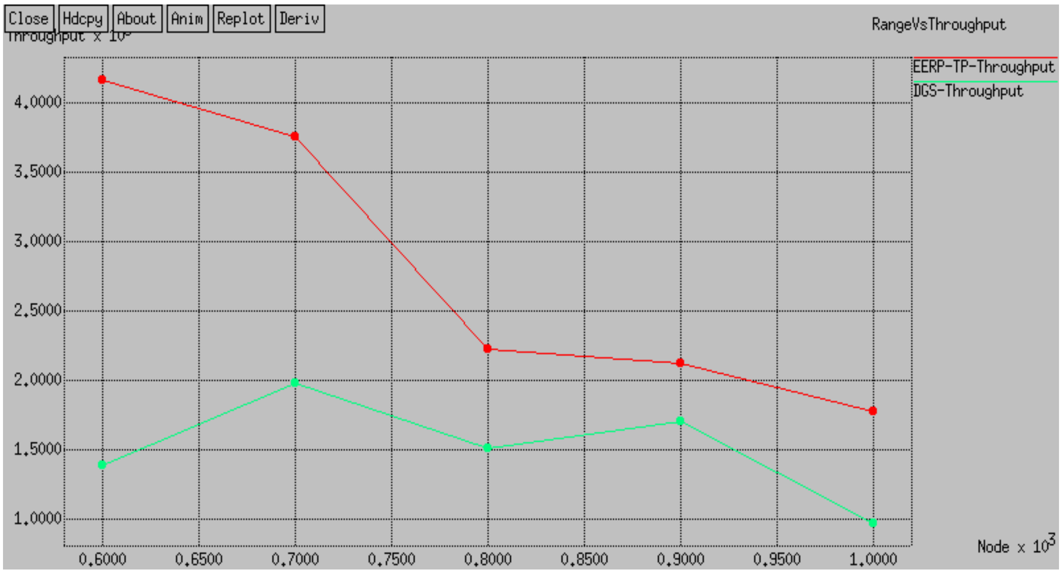


Figure 11 Performance comparison on throughput with different packet size (see online version for colours)



6 Conclusions

In this paper, we have proposed an EERP-TP. The proposed two phases are collective region formation and candidate set selection. The conditional Sierpinski triangle algorithm used to perform the collective region formation and the CMD model used to compute the candidate nodes in the network. The simulation result shows that EERP-TP algorithm performs well in an underwater sensor environment with high density nodes and packet size. The proposed EERP-TP algorithm perform very effective than existing protocols in terms of delay, improved ratio, energy consumption, network lifetime and throughput.

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