Cluster-based Path Planning for Mobile Data Collectors in IoT sensor networks using Artificial Rabbits Optimization

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Abstract
The performance of Mobile Data Collector (MDC) assisted data collection in Internet of Things (IoT) bases sensor networks will be significantly impacted by the placement and clustering of sensors. In large-scale sensor networks, it is crucial and vital to create an effective path planning strategy for MDC. In this paper, Cluster-based Path Planning using Artificial Rabbits Optimization (CPP-ARO) algorithm is proposed for IoT sensor networks. Initially, the network is clustered and the cluster head (CH) is selected by applying ARO algorithm using the parameters node degree, node lifetime and node's closeness centrality. In the next phase, MDC visiting schedule is determined based on the parameters traffic load, buffer occupancy rate, data collection latency and expected energy. Simulation results have shown that the proposed CPP-ARO algorithm attains maximum packet delivery ratio and energy efficiency with minimized delay and packet drops.

Keywords: Internet of Things (IoT), sensor networks, Mobile Data Collector (MDC), Clustering, path planning, Artificial Rabbits Optimization (ARO).

1. Introduction

The phrase IoT has gained popularity because it conjures up images of a vast network of physical items that would allow anytime, anywhere connectivity for everything and anyone. Through technology, the IoT has facilitated easier daily living [1]. However, it has a cost because malfunctions in those systems can result in deadly mishaps and erode public confidence in their reliability. Because of this, the requirement of IoT systems becomes now essential in many situations, especially in critical ones. Even though these systems, hardware, methods, and networks have made significant development, a number of issues still need to be properly resolved [2]. Modern protocols for IoT and WSN applications have been primarily developed to enhance network hierarchy and performance [3]. Applications for the IoT have emerged quickly in a number of industries, including smart homes, healthcare, environmental monitoring and industrial automation etc [4][5].

Data aggregation aims to eliminate redundant data transmissions and so increase network lifetime [6]. It also helps to summarize data from different, disparate and multiple sources. It increases the value of information. Mobile Data Collectors (MDCs) which move over various geographic regions to transport data from sensors to access points are thought to be a more effective way than the traditional data collection techniques employing static sinks [7].

The performance of MDC assisted data collection will be significantly impacted by the placement and clustering of sensors, as well as the choice of data collection mode [9]. In large-scale sensor networks, it is crucial and vital to create an effective path planning strategy for MDC. In MDC path planning problem, data aggregation must be completed in a short amount of time [10].

2. Proposed Methodology

In this paper, Cluster-based Path Planning using ARO algorithm is proposed for IoT sensor networks. Initially, the network is clustered and the cluster head (CH) is selected by applying ARO algorithm using the parameters node degree, node lifetime and node's closeness centrality. In the next phase, MDC visiting schedule is determined based on the parameters traffic load, buffer occupancy rate, data collection latency and expected energy.

2.1 System Model

The IoT sensor nodes are randomly placed on the seabed plane in the network region. The selected cluster head (CH) can gather a lot of data from its cluster members. When the MDC travels close to a CH, the CHs would use RF communication to deliver the stored data to the MDC. Each cluster's sensor nodes are used to choose the cluster head (CH) node. The MDC travels within the network's service area and has a big storage capacity, close communication range, and rapid movement speed. Each CH would be visited by the MDC to receive a sizable amount of data using RF transmission.

2.2 CH selection using ARO

The CH at each cluster can be selected using the parameters node degree , node lifetime and sensor's closeness centrality.

The node degree N_d for the node in range R is expressed as:

$$N_d = \frac{\sum_1^R (n_i, n_j)}{(n_i - 1)} \tag{1}$$

N_j is the total nodes that exists in R, and i and *j* are the two nodes which are 1 if they are connected; otherwise they are 0.

The lifetime of a node is denoted as:

$$N_L = \frac{RE}{ED} \tag{2}$$

where RE is the residual energy of the node and ED is the energy drain rate.

Along with N_d and N_L, the node's centrality N_c is determined as:

$$N_c = \left[\frac{\sum_1^R d(n_i, n_j)}{(R - 1)} \right]^{-1} \tag{3}$$

The distance between the nodes is represented as $d(s_i,s_j)$; this closeness centrality defines the closeness of the particular node to their neighboring nodes.

Then a fitness function is derived from these metrics as

$$Fit() = w_1 . N_d + w_2 . N_L + w_3 . N_c \tag{4}$$

where w_1, w_2 and w_3 are normalized weight constants ranging from 0 to 1.

Then the node with best fitness value is elected as CH by applying the ARO Algorithm which is explained in the following section.

2.2.1 Artificial Rabbits Optimization (ARO) Algorithm

ARO applies the foraging and hiding behaviours of original rabbits. The energy shrink method changes the state into both these concepts [15].

In Detour Foraging (DF), each rabbit searches for food and discard what locates close at hand. ARO assumes that each rabbit in the group contains its own grassy area with d burrows. Also, it is assumed that the rabbits often arbitrarily visit the location of each other for foraging. In reality, rabbits concern around a food source during foraging for obtaining enough food. Hence, in ARO's DF action, each search candidate updates its location towards the other candidates arbitrarily selected in the group and adds a perturbation.

The mathematical equations of DF phase can be derived as:

$$\vec{v}_i(t+1) = x_j(t) + R.(x_i(t) - x_j(t)) + round(0.5.(0.05 + r1)), r1, \quad (5)$$

$$i, j = 1, \ldots, n \text{ and } j \neq i \quad (6)$$

$$R = L.c \quad (7)$$

$$L = (e - e^{(\frac{t-1}{T})^2}) : \sin(2\pi r2) \quad (8)$$

$$c(k) = \begin{cases} 1 & if k == g(l) \\ 0 & else \end{cases} \quad \text{k=1,.....,d and l=1,.....,[r3.d]} \quad (9)$$

$$g = randperm(d)$$

$$n1 \sim N(0,1) \quad (10)$$

Random Hiding (Exploitation)

In ARO, at each iteration, a rabbit produces d burrows in its surroundings along every search space. They generate the j^{th} burrow of the i^{th} rabbit by:

$$b_{i,j}(t) = x_i(t) + H.g.x_i(t), \; i=1,..,n \text{ and } j=1,....d \quad (11)$$

Where H is the hiding parameter given by

$$H = \frac{T - t + 1}{T}.r4 \quad (12)$$

$$g(k) = \begin{cases} 1 & if k == j \\ 0 & else \end{cases} \quad \text{k=1,.....,d} \quad (13)$$

Where $r4$ is a random numbers in (0,1).

Rabbits should find a safer place for hiding for survival. As a result, a burrow is arbitrarily chosen from their burrows for protection from getting caught.
The representation of this random hiding action is represented as:

$$\vec{v}_i(t+1) = x_j(t) + R.(r4.b_{i,r}(t) - x_i(t)), i = 1,....n \quad (14)$$

Based on Eq. (14), the i^{th} search candidate updates its location towards the arbitrarily chosen burrow.
The position update of the i^{th} rabbit is given by:

$$x_i(t+1) = \begin{cases} x_i(t) & f(x_i(t) \le f(v_i(t+1)) \\ v_i(t+1 & f(x_i(t) > f(v_i(t+1)) \end{cases} \quad (15)$$

The above eqn. indicates that the rabbit will drop the current position and hold the candidate position (given by Eq. (14)) when the candidate locations' fitness of the i^{th} rabbit becomes best, when compared to the current one.

Energy shrink (Changing from Exploration to Exploitation)

In ARO, during the starting phase of iterations, rabbits often perform DF, whereas in the later phase, they perform Exploitation. The energy of a rabbit will be resulting from this search mechanism. This will gradually shrink with time lapse. Hence, for modelling the change from exploration to exploitation, an energy factor is computed as follows:

$$A(t) = 4(1 - \frac{t}{T}) \ln \frac{1}{r} \quad (16)$$

2.3 Path planning of MDC

All the sensor nodes from each cluster send their data to MDC based on the following parameters: traffic load at the cluster, data collection latency at sensor nodes, buffer occupancy rate (BOR) of sensor nodes and expected energy of node.
The traffic load (TL) of a node N_i is given by

$$L_i = R_{i.}.DT_i, \ 1 \le i \le N \quad (17)$$

where DT_i is the average data transfer rate, R_i is the arrival rate of packets at sensor buffer b.
Then the load along a cluster is given by

$$L = \sum_{i=1}^{N} L_i \quad (18)$$

The data collection delay (D_{dc}) can be defined as

$$\text{(ie)} \quad D_{dc} = PT + D_{Queue} \quad (19)$$

where D_{queue} is the mean queuing delay.
The BOR of a node is given by

$$BOR = R.\ D_{Queue} \quad (21)$$

The expected energy, $N_{Ex}(\lambda, i)$, is given by

$$N_{Ex}(t,i) = (1 - \log\left(\frac{9X\ E_i(t+1)}{InitialEnergy} + 1\right)) \quad (22)$$

Where $E_i(t+1)$ is the expected energy consumption at time t + 1.

4. Simulation Results

4.1 Experimental Parameters

The CP-ARO algorithm is simulated in NS2. The experimental parameters are presented in Table 1.

Parameters	Values
Network size	50-250
Network size	50×50 m^2
MAC protocol	IEEE 802.15.4
Initial energy	50 Joules
Traffic model	Constant bit rate (CBR) and Exponential
Transmission power	0.5819 J
Receiving power	0.049 J
Propagation model	Two way Ground
Traffic rate	50Kbps
Simulation time	100 sec

Table 1 Simulation parameters

4.2 Comparison Results

The performance of CPP-ARO algorithm is compared with E-ZEAL scheme [11] by varying the nodes from 50-250.

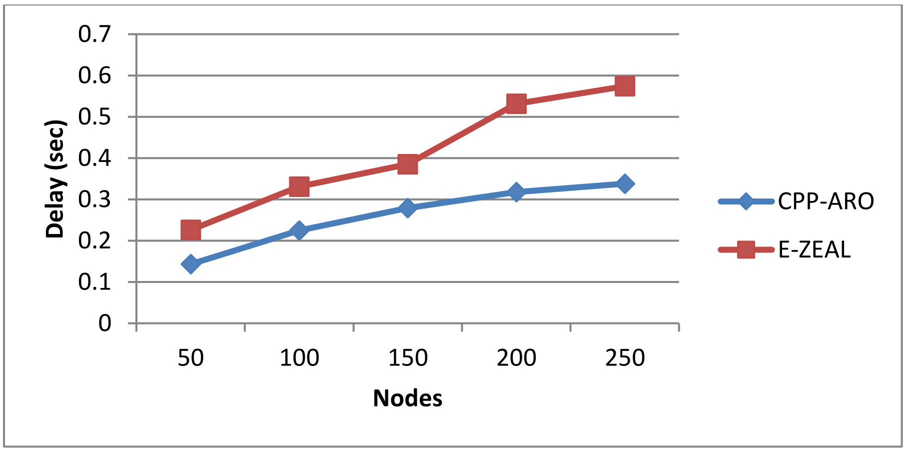

Figure 1 Results of End-to-End Delay

The end-to-end delay results for varying nodes are presented in Figure 1. From the figure it can be see that the delay of CPP-ARO is 35% lesser than E-ZEAL.

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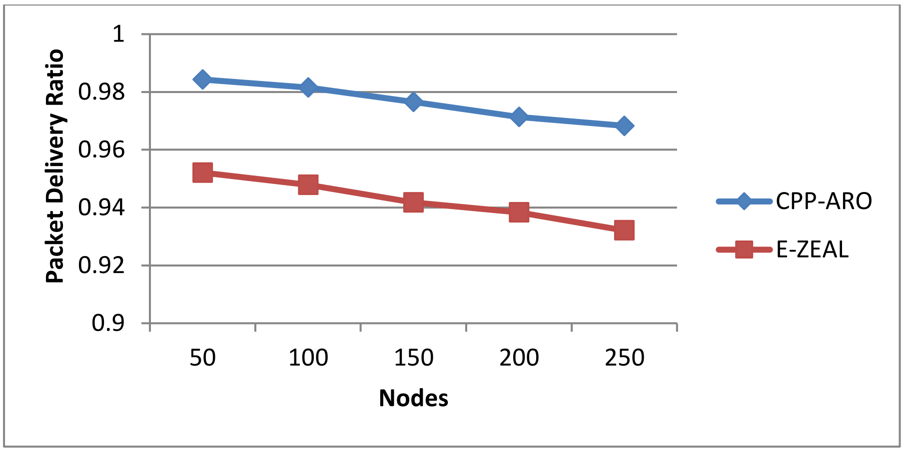

Figure 2 Results of Packet Delivery Ratio

The results of packet delivery ratio for varying nodes are presented in Figure 2. It can be seen that packet delivery ratio of CPP-ARO is 3.4% higher than E-ZEAL.

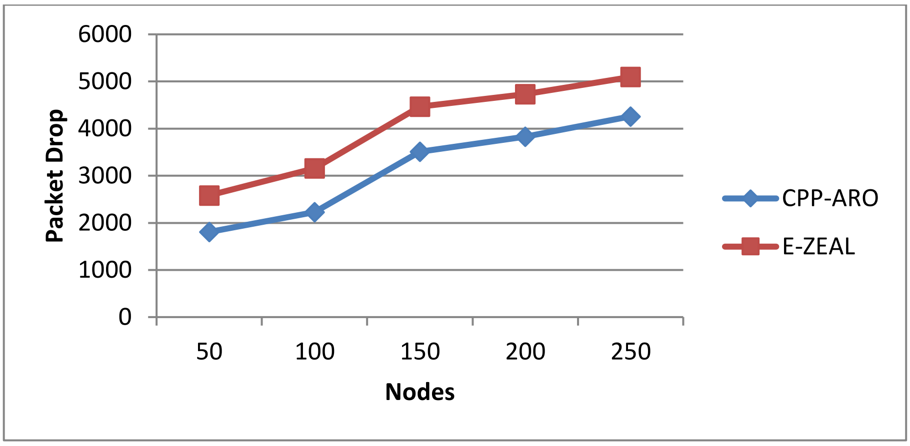

Figure 3 Results of Packet Drop

The results of packet drop for varying nodes are presented in Figure 3. It can be seen that CPP-ARO has 23% lower packet drop than E-ZEAL.

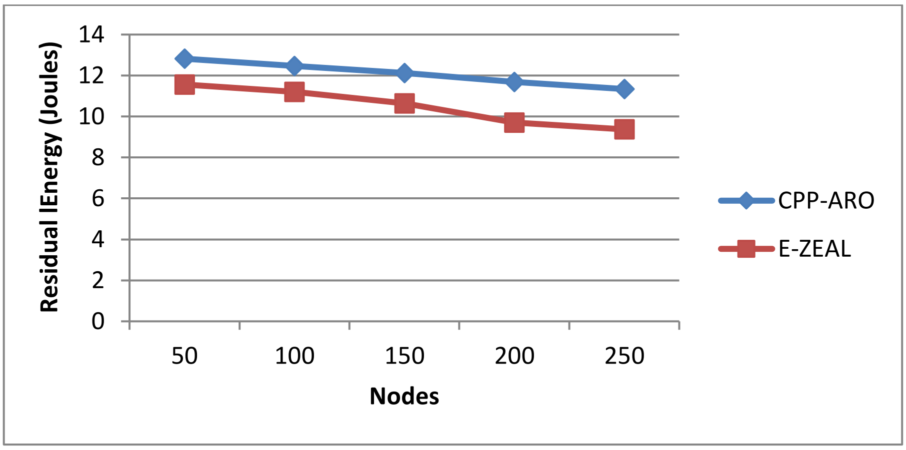

Figure 4 Results of Residual Energy

The average residual energy for varying nodes are presented in Figure 4. It can be seen that CPP-ARO has 13% higher residual energy, when compared to E-ZEAL.

5. Conclusion

In this paper, Cluster-based Path Planning using Artificial Rabbits Optimization (CPP-ARO) algorithm is proposed for IoT sensor networks. Initially, the network is clustered and the cluster head (CH) is selected by applying ARO algorithm using the parameters node degree, node lifetime and node's closeness centrality. In the next phase, MDC visiting schedule is determined based on the parameters traffic load, buffer occupancy rate, data collection latency and expected energy. Simulation results have shown that the proposed CPP-ARO algorithm attains maximum packet delivery ratio and energy efficiency with minimized delay and packet drops.

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