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Optimized Clustering Architecture with TS Algorithm for Intelligent Transportation Systems

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ABSTRACT

Wireless sensor networks (WSNs) as one of the non-negligible components of the Internet of Things (IoT) have proven to be a pillar of the Intelligent Transportation Systems (ITS). The tasks of collecting, processing and fusing the information related to traffic, accidents, congestion and also the detection of pavement distress on roads, are efficiently handled and monitored by WSN-based IoT. However, the energy constraints of the sensor nodes deployed along the roadside, create a perturbing concern for their realization in architecture. Therefore, to address this concern, in this paper, we have proposed an optimized sensing technique that employs two sinks. We term it as Dual sink-based Optimized Clustering Architecture employing Tunicate Swarm Algorithm (TSA), i.e., DOCAT in short. The fitness function of DOCAT integrates the novel fitness parameters for Cluster Head (CH) selection. The parameters are: 1) Residual and initial Energy, 2) Distance of the node from sink, 3) Intra-Cluster Average Distance (ICAD), 4) Network's average energy, and 5) Energy threshold. DOCAT is anticipated to be employed for accident prone roads, from where the critical accidental information is transmitted to healthcare venues through the IoT platform.

Keywords : Wireless Sensor Network, WSN, DOCAT, CH, TSA

I. INTRODUCTION

to INTELLIGENT Transportation Systems (ITS) is a traffic system that orchestrates the information gathered from the roadside and processes it further to preserve on road safety to smooth the flow of traffic [1] [2]. Road transport plays an important role in handling the economic development of a nation as it stretches to reach out the remotest corner of the country and leads to socio-economic integration. According to the most recent report by World Health Organization (WHO), the mortality of around 1.35 million people is reported every year due to traffic accidents [3]. Therefore, there is a need of an automatic monitoring system that can perform two crucial tasks; Firstly, to pact with the traffic congestion and secondly, to report the critical accidental information to the healthcare venues with least delay through Internet of Things (IoT). The role of Wireless Sensor Networks (WSNs) has always been appealing in the context of performing collection, pro- cessing, and fusing the information at low cost, fault tolerant, and easy installation at any desired location pertaining to ITS [4], [5]. Sensor nodes are deployed along the Road Side Units (RSUs), specifically in accident prone areas, wherein these deployed nodes (having crash sensors) gather the information regarding any accident events and send to the Sink from where it is forwarded to the nearest traffic information center for further rescue operations [6]. he sensor nodes exploited for ITS are wireless and suf- fer from limited battery resources and hence, it becomes imperative to adapt energy efficient measures for the data transmission to the sink [7]. The process of clustering of nodes has proven to be potentially promising to elongate the survival period of nodes by abating the number of transmissions. Furthermore, if the sensor nodes are deployed over the large roadside area, the multi hop communication involved among the clustering will lead to the heavy energy drainage of the nodes, i.e., hot-spot problem and hence, the network performance degrades [8]. However, if two sinks are employed for the data collection at the two opposite ends of the road, the effective distance of the nodes from the sink is abated comprehensively.

In our previous work [12], we proposed the Genetic Algorithm-based Optimized Clustering (GAOC) in which three parameters namely, residual energy, distance and node density were integrated in its fitness function. However, it suffered from the inefficient CH selection and traditional GA was employed for optimization. In our other work [13], wehad developed a Tunicate Swarm Algorithm (TSA) that performs comprehensively with its potential exploration and exploitation capabilities, and if the CH selection is optimized through TSA with the additional energy efficient parameters, the network performance is anticipated to be proliferated.

It is noted that when the sensor nodes are deployed for the information dissemination pertaining to ITS, their survival period becomes of utmost concern. Therefore, the optimized CH selection decides the fate of the network that delivers the accidental information belonging to the associated roadside to the healthcare venues through IoT.

A. Main Contributions

To address the concerns, our main contributions presented in this paper can be summarized as follow.

1. A sensing system is proposed that considers the clustering of nodes deployed over the roadside. In other words, Dual sink-based Optimized Clustering Architecture using TSA i.e., DOCAT is proposed for ITS. The fitness function of DOCAT targets novel fitness parameters for CH selection. The parameters are: 1) Residual's and initial Energy, 2) Distance of the node from sink, 3) Intra-Cluster Average Distance (ICAD), 4) Network's average energy, and 5) Energy threshold.
2. The performance evaluation of DOCAT is done against the state-of-the-art techniques pertaining to CH selection and ITS. The surrogate performance metrics are considered as benchmark to investigate the outcomes of proposed DOCAT.
3. To the best of our knowledge, it is the first ever work that reports the CH optimization using TSA that targets particularly ITS applications. Fig. 1 illustrates the pro- posed scenario of DOCAT.
4. Through the extensive simulation we demonstrate that DOCAT outperforms several competitive algorithms in terms of the network reliability, network lifetime, throughput, and energy efficiency.

The rest of the manuscript is organized as follows. Section II details the state-of-the-art work reported in the sensor clustering and ITS. Further, it also gives a brief background of TSA. Section III delineates the operational framework of DOCAT. The simulation results are discussed in Section IV. Finally, the conclusion is reported in Section V.

II. RELATED WORK

WSNs play a vital role in the realization of the ITS through the collection of multifarious information that includes the number of vehicles passing on the roads, events of accidents,

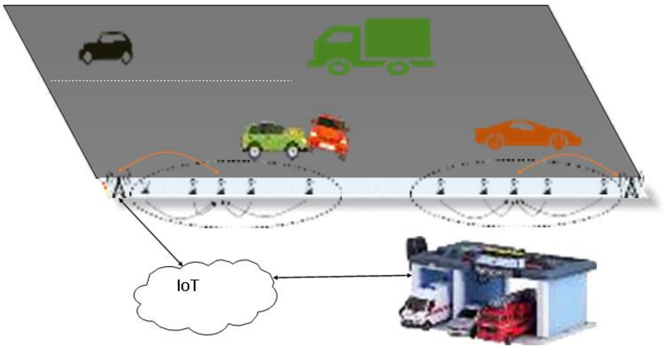

Fig. 1.DOCAT's operation demonstration

weather conditions, etc. Since the development of the WSNs, the energy limitations of the wireless nodes have been of particular concern [14]–[16]. In this section, the initial discus- sion of various studies involving the clustering of specifically the CH selection as well as a brief introduction of TSA are reported. Thereafter, the studies emphasizing the role of WSNs in ITS are discussed.

A. CH selection strategies

A great magnitude of work is reported for the CH selection since the development of hierarchical routing protocols [17]. A comprehensive study for the conventional and meta-heuristic methods for the CH selection technique are discussed in our previous work [12]. However, some of the recently reported state-of-the-art studies are discussed below.

Wang et al. in [18], proposed a hybrid algorithm that moves the sink optimally through the hybrid of Ant Colony Optimiza- tion (ACO), Differential Evolution (DE), and Particle Swarm Optimization (PSO). However, the algorithm suffers from the following pitfalls. The nodes follow multi hop communication that eventually leads to hot-spot problem [8], The number of transmissions are high due to the absence of clustering. The proposed algorithm is a hybrid approach, but without its testing on the benchmark function, the algorithm is subjected to perform for large regions where it could miss the next optimized position of the sink.

Kaur et al. in [19] proposed a Memetic Algorithm-based data collection scheme by involving multiple mobile sinks. The sink collects data based on the nearest located CH. However, the CH with the least energy is ignored while following the closest CH approach that brings the energy imbalance in the network. The investigation of network's remaining energy is also not reported. Tabibi and Ghaffari [20] proposed a PSO- based clustering (PSOBS) in which the sink moved according to the optimized rendezvous points. However, the CHselection is inefficient.

In other attempts, the task of delivering the information to the sink with least delay was taken into consideration by the work reported by Lin et al. In [21] and in our other work [12]. Where, the former proposed priority-aware packet transmission scheduling latter considered multiple data sinks scenario outside the network. The protocol proposed in

[12] i.e., GAOC considered only three factors for the CH selection; energy, distance and node density and hence, it leaves a large scope for the improvement. Sharma et al. in [22] proposed Energy Efficient Trusted Moth Flame Optimization and GA (eeTMFO/GA)-based clustering algorithm. However, it suffered from the major pitfall that included it in the random mobility of the sensor nodes which led to heavy energy drainage of the nodes.

It is discerned from the above reported work and also from our previous studies that there is a need to integrate multifarious energy efficient parameters while designing fit- ness function employed in the potential optimization methods meant for CH selection.

B. Role of WSNs in ITS

The use of WSNs in transportation is an hot research topic over the recent years. [23]–[26]. Thus, the non-negligible role of WSNs in ITS have been reported in the multitudinous work. Tacconi et al. in [4] exploited WSNs for ITS by utilizing three types of nodes; mobile sink, vice-sink, and ordinary sensor nodes in a multi hop communication. As there is no provision for dealing with hot-spot problem, the energy consumption of the network is very high and not suitable for real time ITS [27]. Gaber et al. in [28] proposed Hierarchical Trust-based Secure Clustering (HiTSec) that exploited secured clustering meant for ITS. However, HiTSec considered energy, trust values and number of neighbours for CH selection, but it did not consider the distance factor and many energy efficient factors as well. It is contemplated from the above studies that when WSNs are considered for ITS, the routing pattern has been following the multi hop communication leading to hot-spot problem.

Further, the CH selection still needs to be optimized by considering the various energy efficient parameters.

Therefore, to address the above critical concerns of energy management of sensor nodes and to eradicate the multi hop communication, two sinks are deployed at the opposite sides of the network. Further, the CH selection is optimized using TSA while considering the crucial parameters.

C. Rationale behind employing TSA for CH selection

The main motivation behind employing TSA includes its ability towards acquiring better solutions with enhanced ex- ploitation and exploration capabilities. In other words, a proper balance among its exploitation and exploration features as- sisted it in obtaining globally optimal solutions with better convergence. Also, TSA is more efficient towards solving real life problems in comparison to other algorithms, as discerned from the statistical outcomes of our previous work [13]. Based on these strengths, we chose TSA which is inspired from the jet propulsion and swarm behaviors of tunicates.

A brief overview of TSA is discussed as follow. Firstly, TSA initializes the total iterations count, preliminary parameters and the tunicate's population. Then, the fitness of every search agent is evaluated and the best search agent is explored in the given search space. Later, the position of each search agent is amended and the updated agents are adjusted if they happen to be located beyond the boundary. Following this process, the fitness of updated search agents is computed and the position of previously obtained solution is modified. The algorithm will run up to the stopping criteria and the moment it terminates, it returns the optimized solution.

TABLE I
LIST OF SYMBOLS

Symbols	Definition
Ein	Initial energy of node
Eres	Residual energy of node
N	Total number of nodes in the network
Dn−snk(i)	Distance of ith node from the sink
Dnear	Distance of ith nodes from the nearest node
Dfar	Distance of ith nodes from the farthest node
Dnodes	Number of dead nodes in the network
Nhe	Number of high energy nodes in the network
λ, δ, γ, β σ	Equally weighted variables

III. OPERATIONAL FRAMEWORK OF DOCAT

DOCAT operates by following the steps given in Algorithm

1. The energy of the sensor nodes in the DOCAT is consumed by following the radio energy model specified in [29]. There are some following

presumptions that need to be considered before its implementation in ITS applications.

A. Network presumptions

When the proposed algorithm is realized at the ground level, some of the presumptions considered are stated as follows.

1. In this paper, the network is heterogeneous that considers the nodes with three level of energy heterogeneity. The nodes are called ordinary, advanced and supreme, which are commensurate with the ascending level of energies.
2. The dual sinks are enriched with energy and have no energy constraints. Whereas, the nodes are energy limited.
3. The network is assumed to be secured and the factors related to wireless medium i.e., reflection, refraction and splitting of wireless signal are out of the scope for this work.
4. The IoT architecture is proposed that tends to cover a road of a given size, assumed to be a rectangular in shape where the sinks are deployed exactly opposite at the two ends of the road as given in Fig. 2.
5. The sinks are finally connected to the healthcare venues through the internet i.e., IoT comes into operation once the data is collected by the sinks.

The whole operation of TSA is discussed in [13], when it is subjected to optimize the CH selection; the fitness function decides the fate of the quality of the solution or in other words the optimum selection of CH.

B. The fitness function employed for DOCAT

The fitness function designed for DOCAT is integrated from various individual fitness parameters that consider following essential parameters of CH selection.

1. Residual and initial energy: The first parameter i.e., F1, is one of the most prominent factors for CH selection. The node's energy consumption is commensurate with nature of data transmission with other nodes or sink. Therefore, at each round, the residual or current level of energy is checked for the candidate node for its selection as CH. The equation (1) computes the ratio factor for residual energy of ith node to its initial energy. The lower des = n
2. Distance between the sink and node: The next fitness parameter i.e., F2 is given by equation (2) that computes the ratio of distance between 'the sink and the candidate node' and the average distance of all nodes from the sink. For an energy efficient CH selection, F should be minimized.

$$F_2 = \sum_{i=1}^{n} \frac{D_{n-snk}(i)}{\left(\frac{\sum_{i=1}^{n} D_{n-snk}(i)}{n}\right)}$$

3. Intra cluster Average Distance (ICAD). This fittness parameter i.e., F3, defines number density of the nodes around a candidate node, as it helps in selecting the nodes with maximum number of nodes located nearest to it [19]. The equation (3) computes the distance of the current node from the farthest and nearest node. The third fitness parameter i.e., F3 should be minimized to select the node with highest node density.

$$F_3 = \frac{1}{n} \times \left(\sum_{i=1}^{n} D_{near(i)}\right) \times \frac{1}{D_{far(i)}}$$

4. Network's average energy: The fourth fitness parameter i.e., F4, controls on the number of CHs selected in the network. The equation (4) shows the computation of network's average energy multiplied with the inverse of dead nodes. To achieve energy efficient CH selection, the fitness parameter F4 should be minimized to keep the control over the number of CHs selected.
5. Energy Threshold: The fifth fitness parameter i.e., F5 considers the energy threshold concept for the CH selection. As the network operates, the supreme and advanced nodes are favoured continuously for their selection as CH. However, a moment comes, when these high energy

nodes are left with the comparable energy to that of ordinary nodes and sometimes even lesser. Therefore, the energy threshold is set for these high energy nodes to avoid their frequency.

It is noted that when the sensor nodes are deployed for the information dissemination pertaining to ITS, their survival period becomes of utmost concern. Therefore, the optimized CH selection decides the initiation of the linear combination of the above explained five fitness parameters instead of performing minimization individually. Hence, the fitness function (F) for the TSA- optimized DOCAT algorithm.

```
Input: n = 100, R_max(Maximum number of rounds),
sink1(110, 50), sink2(-10, 50)
Output: A = CH_N, dead_nodes, alive_nodes
1: Heterogeneous nodes deployed randomly in network
2: CH_N = 0 //initialization of number of CH nodes
3: for r (round) = 1 to R_max do
4:   alive_nodes = n
5:   dead_nodes=0
6:   for i = 1 to n do
7:     if E_res(i) == 0 then
8:       dead_nodes= dead_nodes+1
9:       if dead_nodes==n then
10:        all_dead=R_C (current round)
11:      end if
12:      alive_nodes = alive_nodes - dead_nodes
13:    end if
14:  end for
15:  for i= 1 to n do
16:    if E_res(i) > 0 then
17:      Apply TSA algorithm for CH selection
18:      CH_N = CH_N + 1
19:      Near_Sink <-- CH_N
20:    else
21:      i^th node <- TDMA slot for data tx to CH
22:      Update E_res(i) using radio energy model [29]
23:    end if
24:  end for
25:  if dead_nodes=n then
26:    break
27:  end if
28: end for
29: return A
```

C. Explanation for Algorithm

Algorithm 1: DOCAT Algorithm

Line 1 deploys heterogeneous nodes randomly in the network and twp sinks are placed at the opposite sides of the rectangular shaped network. **Line 1** defines the CHN variable that stores the number of CHs. **Line 3-Line 28** cover the whole functioning of the proposed work as the network operates for Rmax number of rounds. **Line 4 and Line 5** initialize the number of alive and dead nodes. Thereafter, **Line 6-Line 14** updates the number of alive and dead nodes. The process of CH selection starts from the **Line 15** as it checks the status of residual energy of the nodes. **Line 17** applies TSA algorithm to select optimized CHs in the network. **Line 18** updates the count to the CHs after the selection of CH and if the node is not selected as CH, it is assigned as cluster member node. Further, a TDMA slot is scheduled for the node as given in **Line 21**. **Line 22** updates the current energy of the node i.e., Eres(i) of ith node. **Line 25-Line 27** monitor the operation of DOCAT for the remaining alive nodes. If the dead nodes are equal to the total number of nodes in the network, the whole network is said to be dead. The corresponding number of rounds is termed as network lifetime. **Line 29** returns the selected CH and status of the alive nodes.

IV. CONCLUSION

WSNs have an unparalleled supremacy when it comes to collect multifarious information from the roads pertaining to ITS. In this paper, a sensing system i.e., DOCAT is proposed that considers dual sink for data collection and optimizes the CH selection using TSA due to it's fast convergence and enlarged diversity'. The fitness function exploited in TSA is delineated distinctively for every constituting fitness parameter for CH selection. DOCAT is specifically designed to acquire accidental critical information from the accident prone roads, which are collected by the sink and hence, forwarded to the healthcare venues. DOCAT is found to be computationally efficient and through the multiple simulations in MATLAB, it is discerned that DOCAT acquires 66.12%, and 29% amelioration in stability period and network lifetime vis-a-vis GAOC protocol, respectively. Further, it also outperforms the HiTsec, eeTMFOGA, and PSOBS routing protocols considering different performance metrics.

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