Asian Journal of Information Technology 15 (5): 921-927, 2016
ISSN: 1682-3915

Intelligent Data Gathering and Energy Efficient Routing Algorithm for Mobile Wireless Sensor Networks

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Abstract: In Wireless Sensor networks, there is a limitation on the packet delivery ratio and energy consumption. Moreover, the data gathering also needs improvement by the use of intelligent techniques. In order to overcome these problems, we propose a new Particle Swarm Optimization (PSO) and cluster based routing and data gathering algorithm for effective data collection and routing in mobile wireless sensor networks. Moreover, a combined metric is used for intelligent routing by combining the traffic load, packet delivery ratio and residual energy. Then, the fitness function of proposed PSO based routing algorithm is able to provide an optimal value by considering the combined metric. The main advantage of the proposed routing algorithm is that it helps to perform load balancing for routing with respect to cluster loads. The cluster head aggregates the data collected from its members and transmits the same to the base station. Through simulation results, we show that the packet delivery ratio is increased and energy consumption is reduced when the proposed routing algorithm is used along with data gathering using PSO.

Key words: PSO, load balancing, cluster head, routing, energy efficient

INTRODUCTION

Recent research in communication has introduced mobility in Wireless Sensor Networks (WSN), since it is advantageous for the user community due to the fact that the mobile nodes can relocate their position after their initial deployment. This helps to achieve the desired density requirement for sensor nodes and also it reduces the energy holes in the sensor network thereby increasing the network life time. A mobile wireless sensor network consists of a collection of tiny sensor nodes each of which has three basic components namely a sensing component which is used for data acquisition from environment using sensors, a processing component for local data cleaning, transformation and storing and finally a wireless communication component for efficient data transmission. Moreover, mobility of these nodes is performed by equipping the sensor nodes with a mobile feature that helps in node movement. Since, mobile wireless sensor networks are more complex to handle than the network with stationary sensors, it is necessary to provide new facilities for energy and routing optimization. This is due to many issues including frequent path breakages because of channel fading, problems from shadowing and interference, node failures due to energy drainage. When an existing path breaks, it is necessary to carry out the route discovery process for re-routing (Huang *et al*., 2006). Therefore, it is necessary to apply intelligent optimization techniques for effective routing in wireless sensor networks.

In the literature, WSN mobility is characterized as controlled or uncontrolled (Khalid *et al*., 2014). Controlled mobility is used for efficient data collection and healing of topological defects. Mobility is deemed to tradeoff delay to achieve energy and resource efficiency. The approach is less suitable for applications with hard real-time constraints (Khalid *et al*., 2014). Various types of routing protocols have been proposed by different researchers in the past for mobile wireless ad hoc networks (Logambigai and Kannan, 2016; Jerusha *et al*., 2012; Anand *et al*., 2012). But, they are not suitable for highly dynamic topologies especially for energy and computation capability constrained sensor nodes. Therefore, prompt path recovery, energy efficiency and robustness are highly preferred characteristics for routing protocols in mobile wireless sensor networks. After initially establishing a path between source and destination nodes, robust routing is able to provide reliable packet delivery against path breakage. Packets can be delivered towards the destination immediately in spite of link break. As a distributed approach, robust routing is relieved from the substantial control overhead

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for route maintenance and update. Light overhead is incurred during the procedure of robust routing (Huang *et al*., 2006).

In this study, we propose an Intelligent Data gathering and energy efficient routing algorithm for effective data collection and routing in mobile wireless sensor networks. This routing algorithm is proposed by the combination of many techniques namely Particle Swarm Optimization (PSO), cluster based routing and data gathering. Here, a combined metric is also used for effective routing by the help of traffic load, packet delivery ratio and residual energy. The proposed system helps to improve the load balancing for routing with respect to cluster loads.

Literature review: There are many works have been done in this direction by various researchers in the past. Among them, Sara *et al*. (2010) have proposed a novel hybrid multipath routing algorithm with an efficient clustering technique. A node is selected as cluster head if it has high surplus energy, better transmission range and least mobility. The Energy Aware (EA) selection mechanism and the Maximal Nodal Surplus Energy estimation technique incorporated in this algorithm improves the energy performance during routing. Khalid *et al*. (2014) have proposed a novel lifetime maximization protocol for mobile sensor networks with uncontrolled mobility considering residual energy, traffic load and mobility of a node. The protocol being generic is equally applicable to heterogeneous, homogenous, static and mobile sensor networks. It can handle event driven as well as continuous traffic flow applications. Shiny and Nagarajan (2012) have proposed an ad-hoc on demand multipath routing protocol for finding multiple paths to transfer the data from source node to destination node. The proposed work performed the energy efficient routing, when the sink node (base station) is in static state and all other neighbor nodes are in mobile state. Here gateway node acts as a relay for transmitting data from one group of node to another group.

Velmani and Kaarthick (2014) have proposed Cluster Independent Data Collection Tree (CIDT). After the cluster head election and cluster formation, CIDT constructs a Data Collection Tree (DCT) based on the cluster head location. In DCT, Data Collection Node (DCN) does not participate in sensing which is simply collecting the data packet from the cluster head and delivering it into sink. CIDT minimizes the energy exploitation, end-to-end delay and traffic of cluster head due to transfer of data with DCT. CIDT provides less complexity involved in creating a tree structure which maintains the energy consumption of cluster head that helps to reduce the frequent cluster formation and maintain a cluster for considerable amount of time. Li *et al*. (2011) have proposed a novel approach for mobile users to collect the network-wide data. The routing structure of data collection is additively updated with the movement of the mobile user. With this approach, they performed a local modification to update the routing structure while the routing performance is bounded and controlled compared to the optimal performance. Their proposed protocol is easy to implement.

MATERIALS AND METHODS

Proposed solution: In this study, we propose to design PSO based routing and data gathering in mobile wireless sensor networks. In inter-cluster routing, a combined metric is derived based on the traffic load, delivery utility and residual energy. Then, the fitness function of PSO is derived based on the combined metric and routing decision is made based on best fitness function, i.e., nodes with better delivery utility, residual energy and minimum load will be selected for routing. Then, load balanced routing is performed from the source cluster head to the base station. Each CH aggregates the data from its members and transmits to the base station such that the flow conservation condition is satisfied.

Estimation of metrics: In this study, we have used three estimation metrics namely traffic load, delivery utility and residual energy which are used for measuring the performance of the proposed protocol based on Khalid *et al*. (2014), Shiny and Nagarajan (2012), Slama *et al*. (2010).

Traffic load: The traffic load of a node is defined using the following Eq. 1 (Khalid *et al*., 2014):

$$TL_0 = \frac{1}{x}\frac{1}{T}\sum_{i=1}^{x}\sum_{t=1}^{T}\eta_i(t) \quad (1)$$

Where:

$\eta_i t$ = Counting function over time interval T
x = No. of old load samples

Delivery utility: The delivery utility is defined as the capability of the sensor node to successfully delivery a message to the sink (Slama *et al*., 2010). Consider DU_s ($0 \le DU_s \le 1$) to be delivery utility of the sensor node s.

- DU_s is initialized with zero
- DU_s value is 1, if it is a sink node

The value of delivery utility is updated as per the following rules:

Rule 1: When a message is transmitted from one sensor node to another node N_i with higher delivery utility, then the DUs is given using the following Eq. 2:

$$DU_s = \beta \times DU_s' + (1-\beta) \times DU_i \tag{2}$$

Where, $\beta \epsilon [0, 1]$ = Predefined constant.

Rule 2: During an issue of higher reachable probability, the sensor possesses only minimum capacity to deliver the message to the sink. When the timer expires, the DUs is updated as follows with aging factor α as follows:

$$DU_s = DU_s' \times \alpha \tag{3}$$

Residual energy: The total energy spent by the transmitter for transmitting x bits message through distance d is given using Eq. 4:

$$E_{tx} = E_e x + E_a x d^2 \tag{4}$$

Where:
E_e = Electronics energy
E_a = Amplifier energy

The total energy consumed by the receiver is given using Eq. 5:

$$E_{rx} = E_e x \tag{5}$$

The residual batter power of each node (E_{res}) following one data communication is estimated using Eq. 6:

$$E_{res} = \left[E_i - \left(E_{tx} + E_{rx}\right)\right] \tag{6}$$

Where, E_i = initial battery power of the node

Particle swarm optimization: Particle Swarm Optimization (PSO) simulated the behavior of foraging birds flying through a collective collaboration between birds to make the groups reach the optimal objective. The core idea is that the individual particles of information among the population of social sharing and collaborative optimization. The concept of PSO is simple and the number of individuals is small, calculation is simple, robustness which shows the superiority in solving complex problems. In PSO system, each alternative feasible solution is called "a particle", a number of particles coexistence, cooperation get an optimal solution (Valle *et al*., 2008). Particles self-updates by tracking the following two "extreme": $P_{best}(i)$ is obtained from the particle itself and known as the individual extreme. $G_{best}(i)$ is obtained from the current population and known as the global optimum. After finding the two optimal values, new velocity λ_i and new location σ_i of the particle are updated as per the following equation:

$$\lambda_i(t+1) = \Omega \times \lambda_{id}(t) + L_1 \times rand() \times [P_{best}(t) - \sigma_{id}(t)] + L_2 \times rand() \times [G_{best}(t) - \sigma_{id}(t)] \tag{7}$$

$$\sigma_{id}(t+1) = \sigma_{id}(t) + \lambda_{id}(t+1) \tag{8}$$

Where:
$1 \le i \le D$, D = Number of initializes particle swarm
$1 \le d \le V$, V = Dimension of searching space
$1 \le t \le D_{max}$, D_{max} = Desired iteration of particle swarm
Ω = inertia weight
L_1, L_2 = Learning factor
rand( ) = Random number in the range {0, 1}

In order to update the individual historical optimal position and optimal location of the particles, an objective fitness function is used and a new individual and global optimal value is obtained as follows:

$$P_{best}(i)\ (t+1) = \begin{cases} P_{best(i)}(t), \text{if fitness } (\sigma_{id}(t+1) \ge \\ \text{fitness}(P_{best(i)}(t)) \\ \sigma_{id}(t+1), \text{if fitness } (\sigma_{id}(t+1) < \\ \text{fitness } (P_{best(i)}(t)) \end{cases} \tag{9}$$

PSO based routing: The steps involved in PSO based routing are as follows: Let J_{in} = {J_{in1}, Jin_2, … J_{inN}} be the Independent jobs. Let, N_i = {N_1, N_2,..., N_n} be the moving resource nodes.

Step 1: Swarm particles (SP_i) are initialized in the network such that the particle's position is randomly dispersed in space. Each SP_i represents a search window equivalent to the nodes position and velocity (λ_i, σ_i,).

Step 2: Each SP_i estimates certain parameters of each node such as Delivery Utility (DU_s), residual energy E_{res} and Traffic Load (TL). Based on the monitored parameters, fitness function (F_i) of each particle is estimated based on below Eq. 10:

$$F_i = (\lambda_1 \times DU_s) \frac{(\lambda_2 \times E_{res})}{(\lambda_2 \times E_{res})} \tag{10}$$

Where, λ_1, λ_2 and λ_3 are the weight values.

Step 3: The local best ($P_{best}(i)$) and global best ($G_{best(i)}$) value of particles and position of each particles is estimated. Thus, the particle includes the following information (Table 1).

Table 1: The analysis of local and global best values

Position	Velocity	Local best value of fitness	Fitness
$\lambda_1, \lambda_2, ..., \lambda_M$	$\sigma_1, \sigma_2, ..., \sigma_M$	P_{best} (i)	F_i

Step 4: The fitness value is sorted and the first half particles that contain low-fitness value move into next generation directly. The second half particle involve in genetic selection and random cross over.

Step 5: If the particles after crossing and adapting are better than before, then update the position of $P_{best}(i)$ with the fitness value F_i or retain the original location.

Step 6: The position of particles in which fitness function is high, are considered as local best and global best values. Update the velocity and position of each particle using Eq. 7 and 8.

Step 7: Update the position of $P_{best}(i)$ and $G_{best}(i)$ based on following condition:

```
If Fi >Fi (Pbest(i))
Then
    Update the position of Pbest(i) with the fitness value Fi
End if
    If Fi > Fi(Gbest(i))
Then
    Update the position of Gbest(i) with fitness value Fi
End if
```

Step 8: The value updated in the global best particle is considered to be best and assigned as best N_i. That is, nodes with better delivery utility, residual energy and minimum load will be selected for routing.

Load balanced routing: Load balancing is an important criterion for improving the routing performance. In such a scenario, the load balance based routing algorithms (Khalid *et al*., 2014) for sensor networks provide increased performance using clustering. Moreover, the sensor nodes select the Cluster Head (CH_p) based on the delivery utility, residual energy and minimum load. The nodes which possess higher delivery utility, maximum energy and minimum load are initially selected as CH_p. These Cluster Heads (CH_p) then broadcast an advertisement message to all its surrounding nodes. The advertisement message includes the CH (ID) appended with Application Packet (APP) and Message Authentication Code (MAC). The packet is authenticated through the MAC code. The non-cluster head nodes first record all the information from cluster heads within their communication range.

Each non-cluster head node chooses one of the strongest Received Signal Strength (RSS) of the advertisement as its cluster head and transmits a member message back to the chosen cluster head. The information about the node's capability of being a cooperative node, i.e., its current energy status is added into the message. The message also includes information related to consistency value, consistent sensing count and inconsistent sensing count of the node.

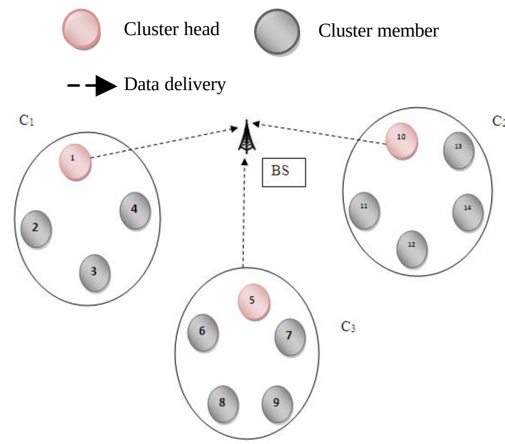

Fig. 1: Inter-cluster routing

If an advertisement message signal is obtained at a CH_p from another CH_q, which has the RSS value greater than a threshold then CH_q will be considered as the neighbor cluster head and the ID of CH_q is stored (Fig. 1). In our technique, CH acts as Data Aggregators (DA_i).

Data aggregation: The steps involved in the data aggregation technique are as follows:

- DA_i sends a Request message (REQ) to a secured node in the list to transmit the actual data
- The particular node that received the REQ message transmits its data to DA_i and the data aggregator does not accept data from any other sensor nodes.
- DA_i aggregates the received data and sends aggregated data to the Base Station (BS) such that the following flow conservation condition is satisfied

Flow conservation: Let, $R_{v,i}$ be the rate at which the data is arrived at the Ch_i. Let, $Q_{v,j}$ be the rate of information of CH_i after aggregation:

$$Q_{v,j} = f_{ag}(R_{v,i}) \quad (11)$$

Where, f_{ag} is the linear aggregation function.

$$f_{ag}(c) = zc \quad (12)$$

Where:
z = Constant, 0<z<1
z = Data aggregation ratio

The average rate of information consists of the generated information rate at $CH_{v,I}$ and information rate received from the neighbor cluster head:

$$R_{v,avg} = Q_{v,i} + \sum_{i/CH_v,j} P_{v,ij} Y_{v,ij} \quad \forall (v,\ i \in \{1,\ \ldots,\ N\}) \tag{13}$$

$$R_v = \sum_{i \in \{1,\ldots,N^{CH}\}} r^{v,i}_{v} \tag{14}$$

Where, $P_{v,ij}$ $Y_{v,ij}$ is the proportion of data transmitted by $CH_{v,j}$ to $CH_{v,i}$.

$$P_v = \{P_{v,ij}\} \tag{15}$$

Equation 14 and 15 verify the flow conservation condition. It states that the sum of the information generation rate and the total incoming flow must equal the total outgoing flow.

RESULTS AND DISCUSSION

Simulation parameters: We used NS2 simulator to simulate the proposed PSO Based Routing and Data Gathering (PREEC) protocol. We used the IEEE 802.11 for wireless Sensor Networks as the MAC layer protocol. It has the functionality to notify the network layer about link breakage. In our simulation, the numbers of nodes are varied as 50,100,150 and 200. The area size is 1000×1000 m^2 region for 50 sec simulation time. The simulated traffic is Constant Bit Rate (CBR). The simulation settings and parameters are summarized in Table 2.

Performance metrics: We evaluate performance of the new protocol mainly according to the following parameters. We compare the LBR (Khalid *et al*., 2014) protocol with our proposed PREEC protocol.

Average packet delivery ratio: It is the ratio of the number of packets received successfully and the total number of packets transmitted.

Average end-to-end delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

Energy consumption: It is the amount of energy consumed by the nodes during the transmission process.

Packet drop: It is the number of packets dropped during the data transmission.

Experimental results: The simulation results are presented in the next section. In our first experiment we are varying the number of nodes as 50, 100, 150 and 200 for CBR traffic.

Table 2: Simulation parameters

Parameters	Values
No. of nodes	50, 100, 150 and 200
Area	1000×1000 m
MAC	802.11
Simulation time	50 sec
Traffic source	CBR
Rate	50 kb
Propagation	Two ray ground
Antenna	Omni antenna
Speed	5, 10, 15, 20 and 25 m sec^{-1}
Initial energy	12.3 J
Transmission power	0.66
Receiving power	0.395

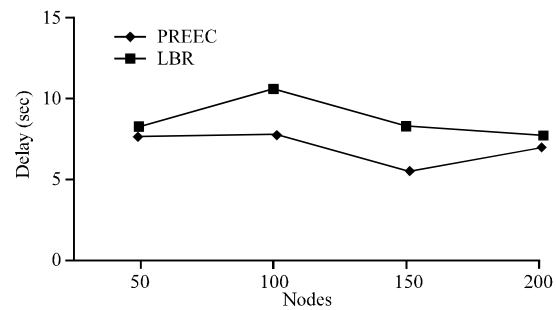

Fig. 2: Nodes vs delay

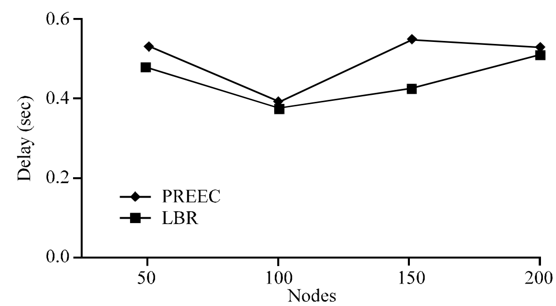

Fig. 3: Nodes vs delivery Ratio

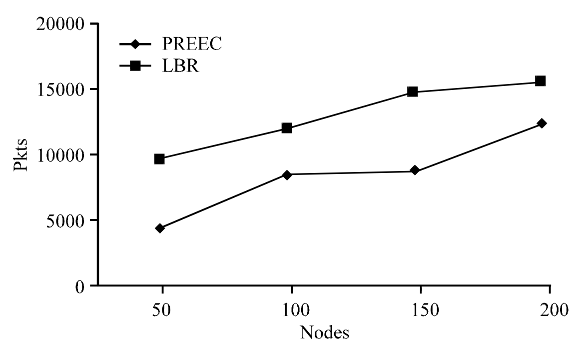

Fig. 4: Nodes vs drop

Figure 2-5 show the results of delay, delivery ratio, packet drop and energy consumption by varying the nodes from 50-200 for the CBR traffic in PREEC and LBR

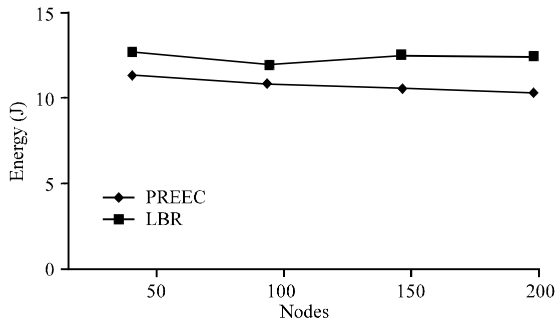

Fig. 5: Nodes vs energy consumption

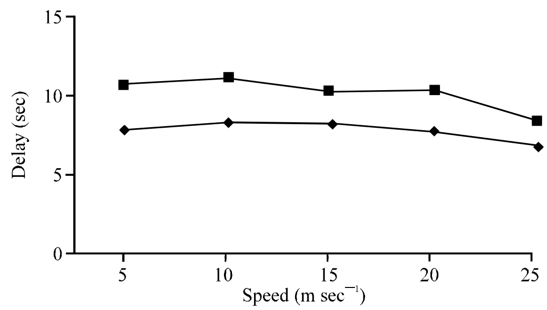

Fig. 6: Speed vs delay

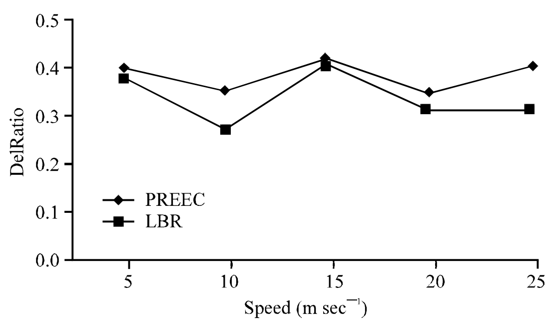

Fig. 7: Speed vs delivery ratio

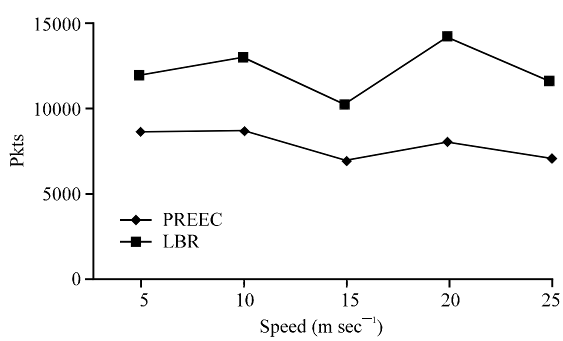

Fig. 8: Speed vs drop

protocols. When, comparing the performance of the two protocols, we infer that PREEC outperforms LBR by 20% in terms of delay, 10% in terms of delivery ratio, 36% in terms of packet drop and 13% in terms of energy consumption. In our second experiment we vary the mobile speed as 5, 10, 15, 20 and 25 m sec^{-1}.

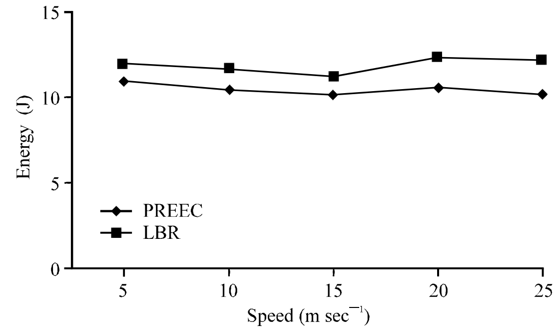

Fig 9: Speed vs energy consumption

Figure 6-9 show the results of delay, delivery ratio, packet drop and energy consumption by varying the speed from 5-25 m sec^{-1} for the CBR traffic in PREEC and LBR protocols. When comparing the performance of the two protocols, we infer that PREEC outperforms LBR by 22% in terms of delay, 12% in terms of delivery ratio, 36% in terms of packet drop and 12% in terms of energy consumption.

CONCLUSION

In this study, we have proposed to design PSO based routing and data gathering in mobile wireless sensor networks. In inter-cluster routing, a combined metric is derived based on the traffic load, delivery utility and residual energy. Then the fitness function of PSO is derived based on the combined metric and routing decision is made based on best fitness function, i.e., nodes with better delivery utility, residual energy and minimum load will be selected for routing. Then, load balanced routing is performed from the source cluster head to the base station. Each CH aggregates the data from its members and transmits to the base station such that the flow conservation condition is satisfied. By simulation results, we have shown that the packet delivery ratio is increased and energy consumption is reduced.

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