Building a Sustainable Internet of Things

Energy efficient routing using low power sensors will meet the need.

By Swati Sucharita Roy, Deepak Puthal, Suraj Sharma, Saraju P. Mohanty, and Albert Y. Zomaya

Internet of Things (IoT) is a framework, built as a network of trillions of devices (called things) communicating with each other to offer innovative solutions to real-time problems. These devices monitor physical environment and disseminate collected data back to the base station. In many cases, the sensor nodes have limited resources like energy, memory, low computational speed, and communication bandwidth. In this network scenario, sensors near the data collector drain energy faster than other nodes in the network. Mobile sink is a solution in sensor networks in which the network is balanced with node energy consumption by using mobile sink in the sensing area. However, the position of mobile sink instigates packet overhead and energy consumption. This article discusses a novel data routing technique to forward data towards base station using mobile data collector, in which two data collectors follow a predefined path to collect data by covering entire network. The proposed technique improves the network performance including energy consumption and sensing area lifetime.

1. INTRODUCTION

Autonomous tiny sensors are spatially distributed to monitor real-time environmental situations like emergency threats and temperature, pressure, sound, pollutants, light, humidity, wind direction in wireless sensor networks (WSN) and IoT [1], [2]. In cyber physical systems (CPS) such as smart cities, smart health, and smart agriculture, IoT uses substantial number of sensors with limited sensing, storage, computing and wireless communication capabilities (Figure 1) [1], [2], [3]. IoT applications include target tracking, environmental monitoring, weather monitoring, disaster management, habitat monitoring, field monitoring, and industrial process monitoring and control. It may be noted that while sensor network (including WSN) and IoT terms are used interchangeably in the existing literature, these are not same things as depicted in Figure 2 with a 3-layer model of IoT [4].

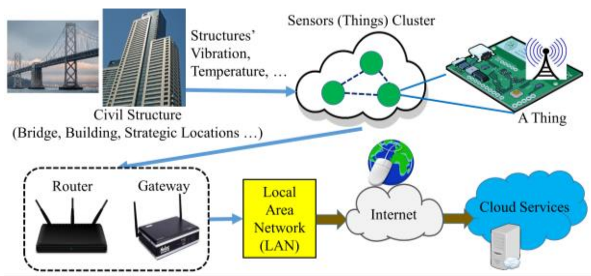

FIGURE 1. IoT for smart structures for smart cities.

A sensor node has several parts including a radio transceiver, a microcontroller, and a battery. A sensor node communicates with other nodes by receiving and transmitting data packets through radio frequency (RF) signals within its transmission range [5]. Source node forwards the sensed data in two different ways: (1) by routing to the nearest sensor to reach the base station or (2) routing the data packets directly to the base station, if the base station is within sensor's radio range. Several algorithms available in the existing literature to optimize routing data packets in WSN from source sensors to the sink nodes or base station. Sensor nodes transmit the sensed data through RF channel to the base station [6]. Sensor nodes have limited battery capacity and replacement of the batteries is challenging in hostile or remote environment.

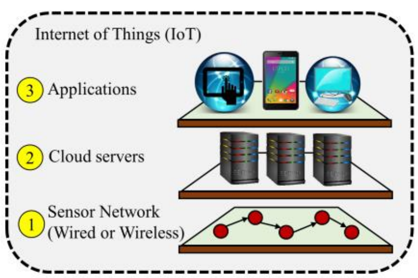

FIGURE 2. WSN versus IoT [10].

Sensor nodes are usually static in the sensing area. The radio range of the sensor node is short, thus multi-hop communication is essential between source sensors and base station. A data collector (i.e. sink in sensor networks) plays a vital role in multi-hop data transmission towards base station by collecting data from source sensing devices. This is also known as device for the fog computing architecture [7], [8]. Nodes nearer to the data collector deplete their batteries faster than other nodes, which is known as energy hole problem [9]. Energy hole problem limits the delivery of the sensor data packets and affects the network lifetime. Mobile data collector is alternate efficient solution to overcome the energy hole problem [10]. Mobility of data collector can maintain load balancing which helps to attain uniform energy consumption and increase in the network life time. Mobile data collector is able to access remote locations of the sensing area, which are unreachable by static data collector [11]. However, mobile data collector requires frequent advertisement of its own position in the network causing more overhead, which need to be minimized to reduce energy consumption. Depending on the application requirements, there are three types of data delivery models: (1) periodic, (2) event driven, and (3) query driven. In periodic sensing, sensors route the sensed data packets continuously in an interrupted interval. In case of event driven data dissemination model, sensor transfers data when an event occurs. In query driven, sensor reports data when data collector requests for the required data.

To address the aforementioned challenge, this article discusses a data routing design by dividing sensing area broadly into two equal parts, either horizontally and vertically to form an elliptical path. There are two mobile data collectors that rotate repeatedly in each side of sensor field in a predefined elliptical path. Mobile data collectors select some sensors to forward data packets from static sources. Data packets are forwarded to data collectors by adaptive neighbor detection and node selection. The mobile data collectors then forward collected data towards the base station. The elliptical path of the collector can be adjusted to maintain load balancing when more sensors are added to the sensing area.

2. STATE OF THE ART

WSN with tiny (low power) sensors for sensing and data forwarding (data routing) in IoT for energy efficiency is addressed in this article. Several data routing protocols proposed for IoT and wireless networks in the existing literature. Traditional ways of data routing towards base station include flooding and gossiping [12]. Flooding means repeated broadcasting, which is a simple and fast technique for data communication. In gossiping routing technique, a sensor node randomly selects one of its neighbors to send data. After receiving data, the neighbor node again selects one of its neighbors to send data.

There are three types of data routing based on finding a route to the destination: (1) proactive, (2) reactive, and (3) hybrid. In a proactive routing protocol, all data dissemination routes to the destination are computed before it is required, while in reactive routing protocol, data dissemination routes are computed when it is required. Hybrid routing protocol is the combination of both proactive and reactive protocol. The mobility model of sensors is classified into three major categories, such as controlled, predictable, and random. In random mobility, data collector arbitrarily moves without depending upon network conditions i.e. network information is not required for mobility. In predictable mobility, data collector's movement is based on certain strategy. It does not require frequent updates of collector's position information. In controlled mobility, mobility of data collector is controlled based on certain criterion like: event position, residual energy etc. Sink controls mobility to reduce energy consumption and increases lifetime of the network. Security plays a vital role in IoT, as sensors are deployed in hostile environment [13], [14].

Based on the mobility of the sink, data dissemination protocol can be further classified into two types: (1) data dissemination protocol with mobile sink and (2) data dissemination protocol with static sink. In a specific protocol example, Railroad constructs a virtual rail structure in the middle of the sensor field [15]. Source node stores sensed data locally and then forwards the corresponding metadata to the closest Rail node inside the Rail as shown in Figure 3. Sink sends query message into the Rail to collect the required data. Railroad increases overhead and consumes more energy as the query message travels through the Rail until it gets the metadata of the required data. In another protocol example, Ring Routing constructs a closed loop taking sensor nodes with single node width around the center of the sensor field as shown in Figure 4 [16]. When energy level of the ring node decreases, it selects another neighbor node as ring node and constructs new ring, i.e. ring structure changes. Mobile data collector selects a neighboring node as an anchor node. After selection of anchor node, position information of anchor node is forwarded to the ring. When source wants to send data to the sink, it sends a request message to the ring for the anchor node position information. Then ring forwards response message.

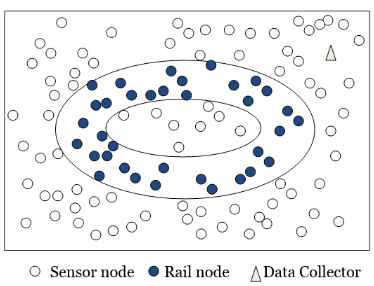

FIGURE 3. Data dissemination in Railroad protocol.

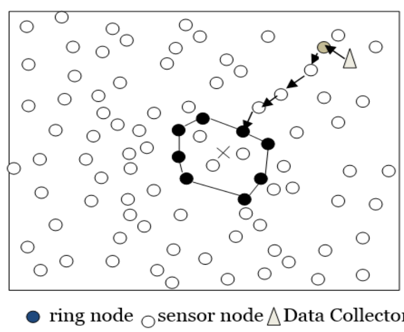

FIGURE 4. Data dissemination in Ring Routing protocol.

3. PROPOSED DATA ROUTING TECHNIQUE

Sensor nodes of the proposed technique play two parts: (1) collector node and (2) normal node. Data forwarding node is the neighboring sensor node selected by the mobile data collectors while rotating in the predefined elliptical path. Except for the forwarding node, all of the sensors in the sensing area act as standard source sensor nodes. After the sensor node deployment, a path is discovered for the mobile data collectors, based on the concept of covering maximum area of the wireless sensor network. In the proposed technique, data collector repeatedly rotates in a predefined elliptical path to collect data from the source nodes through collector nodes and delivers it to the base station.

A. Assumptions

Realistic assumptions have been made to design the routing technique. One of the assumption was to position the base station at the center of the sensing area. A large number of sensors are randomly deployed to sense the sensing area. At the same time, uniform density is ensured such that data gathering rate of each sensor node in sensing area is relatively same. Two mobile data collectors are used to increase the data collection rate and to alleviate the energy hole problem. Base station is always aware about the shape of the sensing area. The sensing area is divided into two equal parts either horizontally or vertically. Each mobile data collector collects data from one of these two parts by rotating in a predefined elliptical path. In case of a square field, an elliptical path can be constructed either horizontally or vertically from the sensor field center, where base station is situated. Similar results are observed for both the cases. However, in case of a rectangular area of the sensor field, some calculations have to be performed before constructing the path for both the mobile data collectors.

B. Protocol Description

The shape of the sensor field has to be found before deciding the elliptical path of the mobile data collector in the sensor field. The sensor field can be square or rectangular in shape. Initially, the base station has the information of the two diagonal points of the sensor field. The base station can find the shape of the sensing area.

In a square sensor field, the sensor field is divided either horizontally or vertically, to construct an elliptical path. However, in a rectangular sensor field, there are two possible cases: (1) in the first case, the rectangle is divided horizontally and (2) in the second case, the rectangle is divided vertically. The new major axis and new minor axis are calculated for each case. The greater value of new major and minor axes of the two cases are compared.

new major axis $(M) = \frac{1}{2} * majoraxis$

new minor axis $(m) = \frac{2}{3} * majoraxis$ (1)

An elliptical path is constructed taking major axis value *M* and minor axis value *m*. Maximum perimeter value of the ellipse is needed so as to cover maximum area by maximizing the perimeter of the ellipse P_{max} on both sides of the sensor field.

$$P_{max} \approx 2 * \pi * \sqrt{\frac{(M^2+m^2)}{2}} \qquad (2)$$

An optimum elliptical path is then discovered for both the mobile data collectors where base station is positioned at the sensing area center. Both the mobile data collectors are deployed in the opposite parts of the sensor field. These mobile data collectors start moving from the base station and collect data packets by rotating periodically. The proposed technique is divided into five parts as the following: (1) partition (horizontal or vertical), (2) ellipse formation for data collectors, (3) collector node selection, (4) neighbor detection, (5) data transmission. These technical descriptions are as follows.

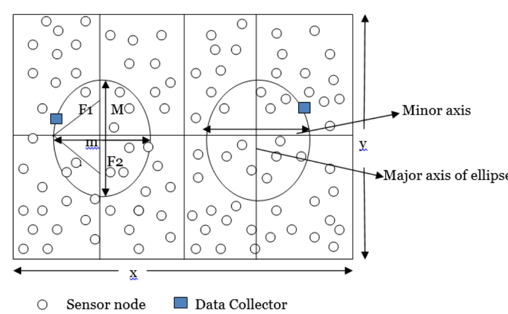

FIGURE 5. Elliptical path construction.

(1) *Partion (Horizontal and Vertical):*

The elliptical path discovery for mobile data collectors are done either by dividing horizontally or vertically as shown in Figure 5. Base station has the information of the two diagonal points of the sensing area. Thus, the base station has X_{max} and Y_{max}, which are the maximum *X* and *Y* coordinate values of the sensor. If $X_{max} \leq Y_{max}$, then sensor field is vertically partitioned; otherwise, there is horizontal partition. The sensing area is thus divided equally into two parts. Sensor node determines its position from this partition information.

(2) *Ellipse Formation:*

After partitioning of the sensing area, each mobile data collector is placed in a separate elliptical path constructed in different parts of the sensing area. The new major axis (*M*) and new minor axis (*m*) can be obtained using Equation (1). For ellipse formation in each partition, major axis value *M* and minor axis value *m* are taken to find major radius and minor radius.

major radius $\left(\frac{M}{2}\right) = \frac{majoraxis(M)}{2}$

minor radius $\left(\frac{m}{2}\right) = \frac{majoraxis(m)}{2}$ (3)

Then the focal point is calculated from the center of the ellipse i.e. linear eccentricity *(f)*.

$$f = \sqrt{\frac{M^2}{2} - \frac{m^2}{2}} \qquad (4)$$

Algorithm 1: Ellipse Formation and Forwarding Node selection
1. if $X_{max} \leq Y_{max}$ 2. vertically partition the sensing area 3. else 4. horizontally partition the sensing area 5. end if 6. $M = \frac{1}{2} * majoraxis$ and $m = \frac{2}{3} * majoraxis$ 7. linear eccentricity: $f = \sqrt{\frac{M^2}{2} - \frac{m^2}{2}}$ 8. construct ellipse by taking the value from step 6 and 7 9. if sensor ∈ data collector neighbor 10. set node as forwarding node 11. include the node in forwarding node list 12. end if

The two focal points (i.e. F_1 and F_2) on the ellipse's major axis have equal distance from the center of the ellipse ($F_1F_2 = 2f$). If any point on the ellipse is taken and the sum of the extension to those two focal points are calculated, it always gives a constant value which is equal to the major axis (*M*) of the ellipse. An ellipse is constructed along both sides of the sensor field as show in Figure 3 by taking the value of major axis (*M*), minor axis (*m*) and the value of *f*. Then, the position of sensor nodes within or outside the ellipse is determined. After the ellipse formation, two mobile data collectors are placed in the opposite part of the sensor field. Both the mobile data collectors rotate in their specified path and collect sensed data from the collector nodes. Algorithm 1 presents steps for ellipse formation and forwarding node selection.

(3) *Data Forwarding Node Selection:*

Data forwarding nodes are the sensors closer to the mobile data collector path. These nodes receive data packets from source sensors through multiple paths. Mobile data collectors select data forwarding nodes in the sensing area before collecting the sensed data from the data forwarding nodes. Mobile data collectors rotate on the predefined path, send beacon message to the neighboring forwarding nodes, and collect the sensed data from the forwarding nodes. Both the mobile data collectors start moving in the elliptical path from the base station and on the first rotation in their assigned path, they select all the neighboring sensor nodes within one hop distance as data forwarding nodes as illustrated in Figure 6. The forwarding node reports to mobile data collector node with neighbor information. If energy level of the mobile data collector node is lower than a threshold, then it selects one of the neighboring non forwarding node (or an old forwarding node) which is within the range of the data collector as the new forwarding node.

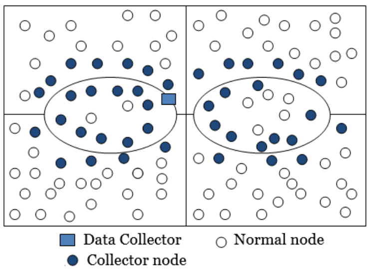

FIGURE 6. Data forwarding node selection.

(4) *Neighbor Detection:*

According to proposed technique, source sensors transmit the data packets to forwarding node followed by data collector collecting data from them by rotating in the predefined elliptical path. Sensor node has two main functionalities: (1) whom to send the data; (2) how to get the direction to send data? Therefore, an important task for source sensors is to determine its neighbors in order to send sensed data.

Sensors have their own position information at the time of node deployment. These sensors determine whether they are within or outside the ellipse using their position information. If a sensor finds its position outside the ellipse, it sends data towards the ellipse center whereas sensors send data away from the ellipse center of that partition if they found their own position inside the ellipse. The clear data inward or outward flow is shown in Figure 7. Later, they find their neighbors after partition of sensing area. The neighbor detection in this technique has two different phases: (a) set-up phase and (b) data collection phase.

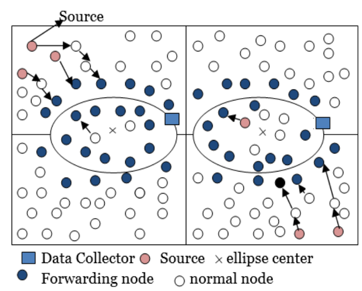

FIGURE 7. Data packets towards forwarding node.

(a) Set-up Phase: This phase contains the procedures to partition sensor field, ellipse formation, and forwarding node selection. Data collectors send beacon messages to its one hop neighbors to get the forwarding node. Sensors respond to the collector node's beacon message if they have enough energy to participate and are also one hop neighbor from elliptic path.

(b) Data Collection Phase: Source node forwards sensed data to the nearest collector node based on its position. Forwarding nodes store the data packets and wait for data collector's presence to forward data. Collector node rotates on the predefined elliptical path and collect the stored sensed data from its neighboring forwarding nodes as shown in Figure 7. Data collector is responsible for data forwarding to the base station based on data sensitive level or distance between them. In worst case, collector node delivers the aggregated collected data to the base station after one rotation.

Algorithm 2: Collection of data from forwarding node by mobile data collectors.

```
if node=collector node
    if data collector ∈ neighbor
        send data to data collector
    end if
else if node=normal node
    if collector node ∈ neighbor
        send sensed data to the collector node
    else
        if source is within ellipse
            send data away from the center of the
            ellipse to the nearest collector node
        else
            send data towards the center of the
            ellipse to the nearest collector node
        end if
    end if
end if
```

(5) *Data Transmission:*

Two mobile data collectors are placed in the predefined path by dividing the sensing area into two approximately equal parts. The mobile data collectors are deployed in either part with base station always present at the center of the sensing area. Both the mobile data collectors start moving from the base station to collect data packets from the forwarding nodes at the time of rotation. These collectors rotate periodically in the elliptical path to collect the data packets from the sensor nodes. After completing one rotation, mobile data collectors aggregate the collected data and finally deliver the accumulation of the collected data back to the base station as stated in last subsection. A procedure of data collection is shown in Algorithm 2.

4. PERFORMANCE EVALUATION

Several simulation environments also exist for IoT and WSN [16]. The Castalia simulator in Ubuntu platform was used to evaluate the performance of proposed data routing technique [17]. The simulation parameters used are shown in Table 1. The performance of the proposed routing technique is compared with Ring Routing protocol [18].

Table 1: Simulation parameters.

Simulation Parameters	Values
Simulator Used	Castalia Simulator (version 3.2)
Network area	600*600m^2
Number of nodes	200
Max radio Transmission power	0dbm
Sensibility	-95dbm
Simulation time	600s
MAC protocol	Tunable MAC
Initial energy of nodes	1000mJ
Data collector speed	3, 6, 9, 12, 15 km/h
Number of data collector	2

A. Average Control Packet Overhead

In order to manage the data collector mobility, sensors transmit the control packets for rendezvous region construction. Figure 8 shows the average control packet overhead with varying data collector speed. The proposed technique, reduces the usage of control packets as compared to the Ring Routing protocol. In Ring Routing, the ring nodes always keep the location of the sink, which allows for easy retrieval of sink location. However, as network operation progresses, there is always need for control packet exchange to repair the ring. An increase in the distance between source and sink leads to higher energy consumption for the increased ring length.

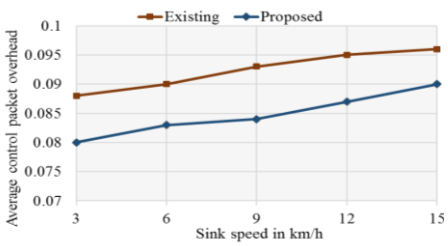

FIGURE 8. Variation of average control packet overhead with data collector speed.

B. Average Energy Consumption

Average energy consumption of a node is the energy consumed in transmitting and receiving data packets and control packets in a network. Energy consumption of routing protocols should be reduced in order to improve the network effectiveness. In this experiment, average energy consumption was measured by varying data collector speed from 3 km/h to 15 km/h in increments of 3 km/h at a constant simulation time of 600 s. Average energy consumption for the proposed technique is less than the existing standard mobile sink protocol as shown in Figure 9. Average energy consumption shows the lifetime acquired by the technique.

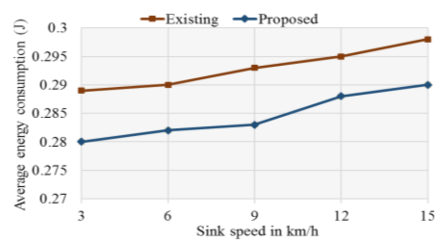

FIGURE 9. Variation of average energy consumption with data collector speed.

C. End-to-End delay

The time taken to find the data collector's location and then forwarding the data packets to the collector node is a time consuming task. End-to-end latency of the network of the proposed protocol in comparison with existing protocol is shown in Figure 10. In the proposed model, source sensors forward data to the forwarding node followed by data collector collecting sensed data when the forwarding nodes are within its radio range. As a result, the end-to-end delay of the proposed technique is very less compared to existing protocol. End-to-end latency of the network of the proposed protocol in comparison with existing protocol is shown in Figure 10.

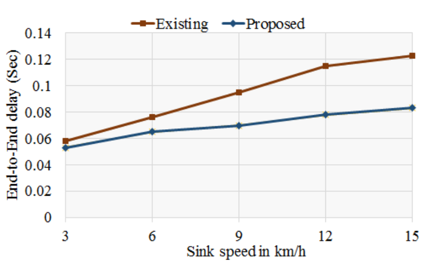

FIGURE 10. Variation of end-to-end delay with data collector speed.

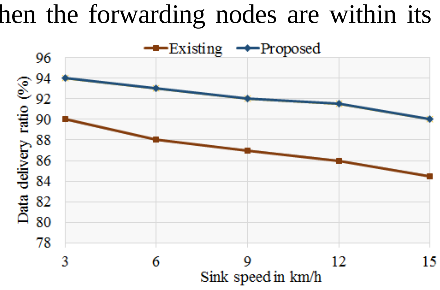

FIGURE 11. Variation of packet delivery ratio with data collector speed.

D. Packet Delivery Ratio

Packet delivery ratio is the ratio of received packets to the packets delivered. This ratio is always counted in percentages i.e. number of packets delivered when hundred packets are sent from source sensors. The proposed technique needs less time to get the data collector's location when compared to Ring Routing. Ring Routing introduces delay while forwarding data packet towards the base station. In that duration, the data collector may change its location by selecting next movement causing data loss. In the proposed model, data collector's location information is not required; when sensor node senses data, it forwards that data to the forwarding node decreasing packet loss. Therefore, the proposed technique has better packet delivery ratio compared to other protocols. As shown in Figure 11, the packet delivery ratio performance of the proposed model is always efficient and better compared to Ring Routing protocol.

E. Network Lifetime

Network lifetime refers to the time taken till the first node dies in the network. Network lifetime plays a vital role when time sensors are used to sense the network. In a specific experiment, network lifetime is measured by considering number of nodes (200 nodes) died in the sensing network by varying the simulation time from 100 s to 600 s. The comparison result between the existing and proposed technique for network lifetime is shown in Figure 12. The proposed technique has longer network lifetime than the Ring Routing protocol. The proposed protocol uses less number of control packets resulting in load balance among the sensors and follows an optimum route for data packet dissemination.

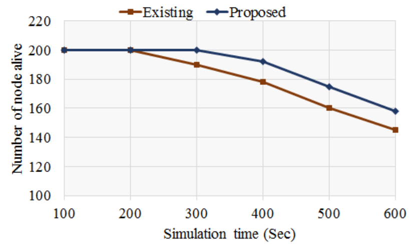

FIGURE 12. Variation of network lifetime with simulation time.

5. CONCLUSION AND FUTURE DIRECTION

In IoT, small and tiny sensors are deployed to sense the networks, where sensors have limited battery capacity and replacement of the batteries is an effortful task. In such a situation, the main challenging issue is the better utilization of the limited energy of the sensor node to prolong network lifetime. Energy constraint sensor was the major design focus of this paper. In the proposed routing, two mobile data collectors are used to collect data from the sensor field, which is divided into two partitions. Mobile data collectors rotate on the predefined elliptical path; Mobile data collectors collect data from individual sensors, send beacon message to the neighboring forwarding nodes, collect the sensed data from the forwarding nodes, and deliver the collected data to the base station located at the center of the sensor field. The performance of the proposed routing is superior in terms of average control packet energy consumption, average energy consumption, data delivery latency, and low end-to-end latency. This routing technique solves the energy-hole problem has great potential for IoT applications.

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