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LQOR: Link Quality-Oriented Route Selection on Internet of Things Networks for Green Computing

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***Abstract*—Recently, Internet of Things (IoT) has witnessed significant attention due to its potential of interconnecting massive number of heterogeneous sensor nodes to collect big data for harnessing knowledge thus enabling real time monitoring, actuation and control. The wireless sensors relay their packets on to the base station via multi-hop transmissions and the overall functioning of the system, therefore, is dependent on these intermediate nodes. However, unbalanced data forward amongst the nodes results in high-energy consumption and packets drop. The network lifetime and link reliability are the most important factors for the network to work for longer period of time, hence optimum selection of the paths for packet routing is key for prolonged network life. This paper proposes a link quality-oriented route (LQOR) protocol for scalable IoT networks. The main goal of this scheme is to balance the network load by intelligently selecting the next hop with less number of neighbouring nodes. The comparative performance evaluation corroborates the positive impact of the algorithm as compared to other related techniques existing in the literature. We show that the proposed algorithm achieves less packets loss and average number of paths, minimizing data retransmissions. This effectively improves the overall system performance and elongates the network lifetime.**

***Index Terms*—Internet of Things (IoT), Link Quality, Link Reliability, Green Computing, Packets Loss, Wireless Sensor Network (WSN), Network Lifetime.**

I. Introduction

Internet of Things (IoT) is a collection of massive number of smart devices with the ability to communicate with each other through the internet [1]. It has the potential to be implemented in various applications areas for real time monitoring, actuation, automation and control. Figure 1 depicts some of the areas that benefit from the new technology. IoT has enticed a great deal of attention from various stakeholders including governments, industries and academics. With the ever increasing devices being connected to the internet, problems and challenges faced by the area of IoT are also growing. These challenges include issues such as cyber security, strict energy consumption requirement, scalability, heterogeneity, etc.

Wireless sensor networks (WSNs) is one of the key enabling technologies for IoT [2]. In WSNs, thousands of physically embedded sensors are deployed randomly allowing to sense over a large geographical area with great accuracy. The sensing nodes in such a network use single or multiple hops technique to deliver their packets to the ultimate receiver [3]. The transmission range for these devices can be upto few meters and it is a well known fact that the transmission consumes energy [4], therefore, it is quite significant to implement an optimal routing strategy such that retransmission may not be required and necessary. The routing protocol controls the decision on forwarding the packets to the next node and in a large network, suitable routing strategy needs to be adopted for disseminating the data via the suitable path and balance the load within the network [5]. Without the proper load balancing in the network, there will be a risk of certain nodes dying quicker thus leaving certain areas of the network uncovered.

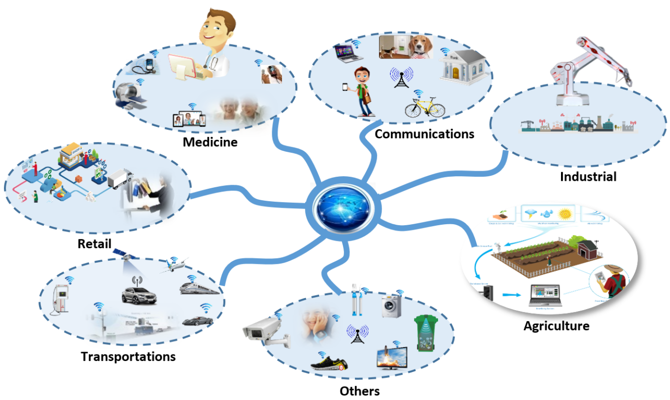

Fig. 1: Network of the Future.

Efficient routing protocol for WSNs enabling green computing has attracted significant attention recently and presents unique challenges in the area of WSN and IoT applications [6, 7]. Various routing protocols have been investigated and proposed in recent years [8, 9]. Such schemes can achieve energy efficiency during the data collection and processing, thereby, increasing the sustainability of the WSNs and IoT networks. Various strategies include to consider node lifetime, placement, capabilities, mobility and others.

The work in [10] proposes the balanced-energy-adaptive-routing (BEAR) to reduce the energy consumption and thus prolong the lifetime of the network. In this protocol, all nodes share the information related to their locations and residual energy. In order to balance the power usage among nodes, BEAR selects a node according to higher residual energy. In [11], the authors clustered the network into sub-groups and each group is assigned with a single cluster head (CH). The rule on how to elect the CHs is based on the broadcast message between the nodes that includes energy level of each node. Also, spanning routing tree is constructed within multi-hop technique on the CHs to process the data that gathers from the nodes and forward it to the base station.

As highlighted by [12], authors introduce the novel energy aware routing that aims to elongate the network lifetime for IoT applications. The proposed scheme utilizes RPL routing function and expected transmission count (ETX) metric. It balances between the number of packets transmitted successfully and remaining energy of each node. The results show that improve around 30% overall for a uniform network sensors in term of network lifetime. However, authors in [10–12] do not consider the neighbouring nodes of the individual node and CHs. A node or CH linking with greater number of neighbouring nodes requires higher processing time and bandwidth to serve the data. Thus, packets are queued resulting in some of packets loss and retransmission due to time out and limited resources of the nodes.

ETX [13–15] measures the quality of a link between two or more nodes in a wireless data communication. ETX of a path searches for the less expected number of transmissions of a packet (including re-transmissions) to disseminate data to its destination. It presumes a reliable connection with less transmission cost and a high throughput for end-to-end communications. However, it may not always be true as elaborated in the Fig. 2.

A simplified example with two paths of ETX has been shown and explained in Fig. 2. Both ETX paths have route equal to 9. However, nodes in these paths have unbalanced links. For example, $nodeA$ located in $path2$ has more links connected to it. This means $nodeA$ will be overloaded quicker. Such an overload requires more time to process the packets, high bandwidth and memory causing greater energy depletion and latency. Therefore, the probability that a packet passes through $path1$ is higher than $path2$. In this case, the ETX technique fails to capture the link reliability.

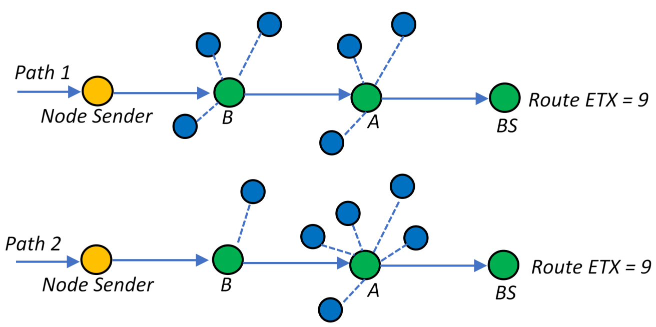

Fig. 2: Two paths of ETX route.

In [16], authors introduce a tree based mobile sink (TBMS) for multi-hop WSN communication. The main goal for this scheme is to reduce the transmission distances of nodes by creating tree structure and multi-hop concepts. The technique shows best performance compared to other techniques. However, the mobile sink has random movement, therefore it takes time to cover and sense the area. It also there is no guarantee to reach all sensors in the field. Furthermore, if the speed of mobile sink is slow or high, then it may cause the packet loss or data delay if the speed of MS is slow and thus retransmission of packets happen.

In the wireless adhoc networks, it is decentralized to route the packets from the source to target. It also does not need any particular infrastructure such as backbone, access points, etc. Ad hoc On-Demand Distance Vector (AODV) routing is being one of the standard protocols in wireless adhoc networks. It uses when two or more endpoints do not have a valid active route to communicate each other [17]. In another study [18], dynamic source routing (DSR) is a routing protocol for wireless mesh networks. It is similar to AODV protocol where it forms a route on demand when transmitting packets. However, it uses source routing instead of relying on the routing table at each intermediate node.

In this paper, link quality oriented route selection (LQOR) is proposed for a large scalable networks. This routing scheme differentiates between the nodes on the path and chooses the node that has less number of neighbouring nodes to be the next hop. By doing so, the scheme balances the load throughout the network and minimizes the probability of overloading only few nodes.

The rest of this paper has been summarized as follows: In section II, a description of the strategy of LQOR protocol is presented together with mathematical modelling. The simulation model, results, and discussion have been provided in section IV. Finally, we conclude this paper in section V.

II. System Model

The main goal of this work is to implement a new routing technique that minimizes the energy usage for the IoT sensors and increases the lifetime of these networks. Battery power can be balanced by efficient data traffic management. Therefore, it is important to find a suitable technique that can manage and balance a heterogeneous data generated by IoT-sensors. The proposed system utilizes a typical IoT architecture shown in Fig. 3. We assume that SNs are deployed randomly in the sensing field. N is the total number of sensor nodes in the system model and d_i is the distance between two nodes given by Euclidean mathematical method as:

$$d_i = \sqrt{((x_i - x) + (y_i - y))^2}, i = 1, 2, 3, ..., N \quad (1)$$

where (x, y) is the location of each node. Nodes gather the information from the environment and send it to their respective CH which collects, compresses and then forwards it to the BS. BS is responsible for delivering the packets gathered by sensor nodes to the human centered applications via the internet and communication infrastructure.

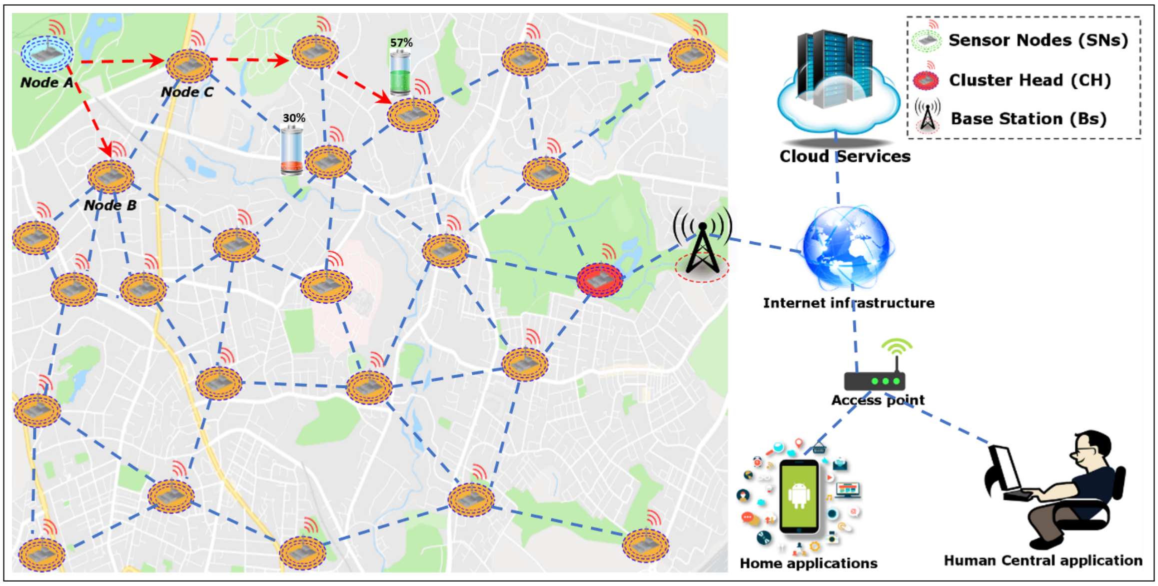

Fig. 3: Typical IoT system architecture.

During the packets journey, the probability of drops increases due to the high number of paths linked to a single node, interferences, limitation of the processing unit and bandwidth. Therefore, a suitable routing protocol is highly recommended in terms of higher energy utilization and maintain a longer network lifetime.

A. Link Quality-Oriented Route (LQOR) Selection

As we mentioned earlier, all data obtained from the sensor nodes should be transmitted to the BS. Therefore, we assume that the BS has unlimited power source. The computation and route selection of the LQOR are done at the BS. It acquires the geographical information related to nodes when the network is first set up. LQOR scheme is divided into two phases:

- **Phase 1:** Base station and sensor nodes require to exchange hello message (msg) before actual data communication begins. This is to collect and share the locations information and other important details of SNs with BS. The BS analyses these data coming from the SNs and then broadcasts the information table (IT) to the CHs nodes which in turn forwards to all its nodes using multi-hop technique.
- **Phase 2:** By constructing the IT packets that contains number of neighbor nodes and energy level to each node, any node in the network can select by itself the next hop to disseminate their packets. Let's say a node has two paths to forward their packets to the next target. The next hop node on $path1$ has number of neighbor nodes $N_1(p) < N_2(p)$ on $path2$. Therefore, a node decides to pick $N_1(p)$ as a forwarder path based on step 15 in pseudo-code. Step 17 clearly reveals that if $N_1(p) == N_2(p)$, thus the LQOR takes into consideration the second parameter which is the average residual energy of each node.

Algorithm 1 :Pseudo-code for LQOR Strategy

Initialization
Set $N_n(p)$ = neighbor nodes $(N_1(p), N_2(p), ..., etc.)$
Set SNs = number of nodes
Set $E_{residual}$ = average residual energy

1: **procedure** $Phase1$: ROUTE DISCOVERY
2: **for all** SNs **do**
3: **if** $SNs \in N_n(p)$ **then**
4: $SNs\ send\ msg\ packets$
5: **else**
6: $SNs \notin N_n(p)$
7: **end if**
8: **end for**
9: **for all** $N_n(p) \in SNs$ **do**
10: $N_n(p)\ reply\ to\ SNs$
11: **end for**
12: **end procedure**
13: **procedure** $Phase2$: GEOROUTINGLQOR
14: **for all** $SNs \in N_n(p)$ **do**
15: **if** $N_1(p) < N_2(p)$ **then**
16: $Select\ N_1(p)\ as\ the\ next\ hop$
17: **else if** $N_1(p) == N_2(p)$ **then**
18: **if** $E_{residual}(N_1) > E_{residual}(N_2)$ **then**
19: $Select\ N_1(p)\ as\ the\ forwarder\ path$
20: **else**
21: $N_2(p)\ is\ the\ next\ path$
22: **end if**
23: **else**
24: $Select\ N_2(p)\ as\ the\ next\ hop$
25: **end if**
26: **end for**
27: $Forward\ packets\ to\ the\ target\ node$
28: **end procedure**

Let $E_{residual}(n)$ is the average residual energy level of a node and $Npath$ is the number of paths to a node, then the average residual energy of each node can be calculated based on eq.2.

$$E_{residual}(n) = \frac{T_E}{N_{path}} \tag{2}$$

Where T_E is the total energy of a node. The node with $N_1(E_{residual}) > N_2(E_{residual})$ is selected as the next hop to deliver their packets to the target as depicted in step 18 of algorithm 1. Let us consider the scenario shown in Fig. 3. We suppose that $nodeA$ wants to forward a packet to the BS. It has $NodeB$ and C forwarder paths to select from. However, the immediate neighbouring nodes of C is less than B. Many links to an individual node lead to quicker energy drainage. Therefore, a node with higher number of neighbour nodes has less energy, bandwidth, higher processing time and interference. Thus, $nodeA$ delivers it packets to $nodeC$ and then through the intermediate nodes based on LQOR strategy to reach the ultimate receiver. This describes in algorithm 1.

B. Energy Consumption Model

A common power model [19] is used and shown in Fig. 4. LQOR is implemented to find the path with less number of links and neighbouring nodes to forward the packets. The total energy [19] can be calculated using the following equations.

- To transmit $m - bits$ of data:

$$E_{Tx} = m(E_{elec} + \epsilon_{amp} * d^2) + E_{gps} \tag{3}$$

- To receive $m - bits$ bits of data:

$$E_{Rx} = m(E_{elec} + E_{da}) \tag{4}$$

- Then the total energy used by a particular node is:

$$E_{Total} = K(E_{Tx}) + F(E_{Rx}) \tag{5}$$

Where E_{tx} and E_{rx} are the energy depleted due to the transmission and receiving $m - bits$ of data from the source to next hop respectively. d is the distance between two objects and E_{gps} is the energy dissipated for GPS receiver. E_{elec} is the energy wasted to run the circuit (transmitter or receiver). K and F are the number of hops for transmission or receiving on a sensor respectively. E_{amp} is the energy used to amplify the signal to reach the next target. E_{da} is the energy depletion for data aggregation and compression.

ϵ_{amp} is the power wasted in the transmission unit to amplify the signal enough to reach the next target that can be calculated as:

$$\epsilon_{amp} = \begin{cases} \epsilon_{fs} * d^2 & d \leq d_0 \\ \epsilon_{mp} * d^4 & d > d_0 \end{cases} \tag{6}$$

$$d_0 = \sqrt{\frac{\epsilon f_s}{\epsilon_{mp}}} \tag{7}$$

where ϵ_{f_s} is the amplification coefficient of free space signal (d^2 as power loss) and ϵ_{mp} is the multi-path fading signal amplification coefficient (d^4 as power loss). d_0 is a threshold value calculated by eq. 7 [16]. When the d is less than d_0, then a free space propagation method is used. In case, if a node is a quick depletion or addition, this drastically will affect the behavior of LQOR protocol. Therefore, new routes can be available at the selection time based on $phase1$ of LQOR algorithm.

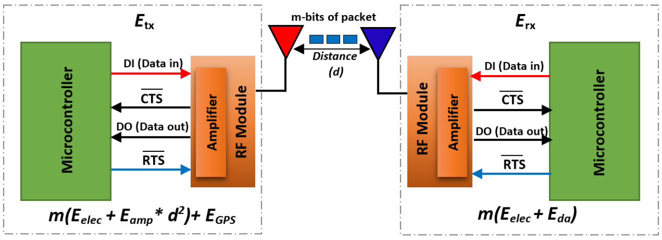

Fig. 4: The wireless communication power model.

III. Results and Discussion

The proposed protocol, ETX, and TBMS techniques have been compared via $Matlab$ simulation to analyse and evaluate the system performance of IoT-devices in term of energy usage. IoT consists of heterogeneous technologies and spread in a large area to achieve a specific service. Therefore, the simulation is performed with 100 nodes distributed randomly in an area of (300 x 300)m^2. The parameters and assumption used in the simulation are shown in the table I.

TABLE I: Parameters used in the simulation

Parameter	Value
Electronics Energy (E_{elec})	50 nJ/bit
Initial energy of node (E_{init})	0.25 J
Energy of data Aggregation (E_{da})	5 nJ/bit/signal
Energy for GPS (E_{GPS})	20 nJ/bit/signal
Communication energy (ϵ_{fs})	10 pJ/bit/m^2
Communication energy (ϵ_{mp})	0.0013 pJ/bit/m^4
Threshold value of distance (d_0)	87 m
Payload size + Header Size	2000 bits
Retransmission overhead size	8 bytes + header size
Number of nodes (N)	100
Sensing Area	300m^2

The aim of the proposed protocol in this paper is to optimize energy consumption and the communication towards neighbor nodes and thus extend the network lifetime. The proposed scheme has been compared with ETX and TBMS techniques in order to understand the efficiency and evaluate the performance of the LQOR algorithm. Connectivity is an important requirement for IoT devices especially in data collection and transfer applications. Many different paths to the target means high tolerance against failure, however it consumes node resources and bandwidth. Therefore, it is important to reduce the number of paths to optimize the power uses. Figure 5 illustrates the comparison of the LQOR protocol against other scenarios in term of number of paths to the BS. The proposed scheme realizes 7.8% and 16.9% overall reduction as compared with existing protocols TBMS and ETX respectively. On the other hand, figure 6 shows

1.03% and 1.8% improvement in total transmission distances as compared to TBMS and ETX schemes respectively. Furthermore, we measure the energy consumption for each round. The proposed scheme successfully balances the energy amongst all nodes and reduces the energy dissipation. This is depicted in the Fig. 7 which shows that LQOR achieves lesser energy consumption per round than other schemes.

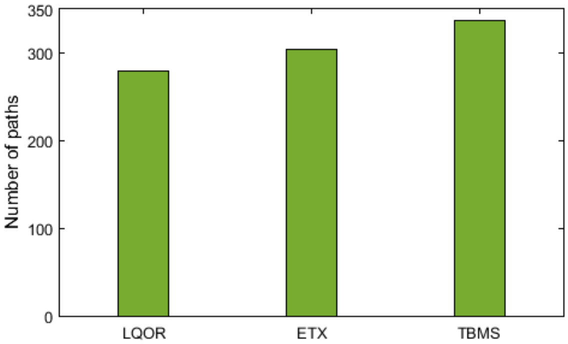

Fig. 5: Number of paths.

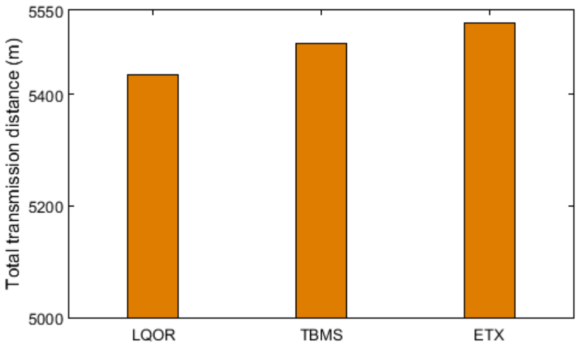

Fig. 6: Total transmission distances (m).

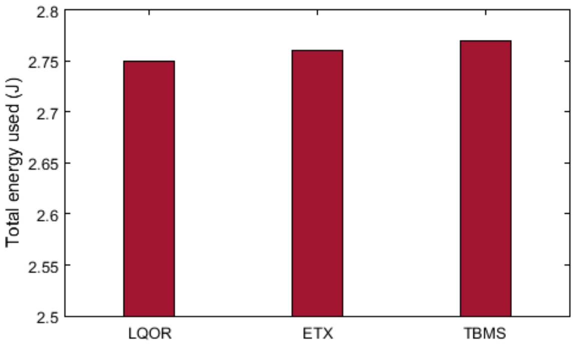

Fig. 7: Energy consumption *per* a round (J).

In Fig. 8, we plot the overall energy consumption of the network with increasing rounds. It is evident that the energy consumption of our scheme outperforms than other two methods. Until around 690 rounds, all methods perform almost similarly. This is because at the beginning, the nodes are fully powered. However, when the number of rounds increases, i.e. when power in the nodes have started to deplete, ETX performance begins to degrade. Round 710, TBMS also start to consume more energy illustrating that it fails to balance the load efficiently. LQOR reduces the number of paths and transmission distances and this clearly also reflects in the total energy consumption of the network.

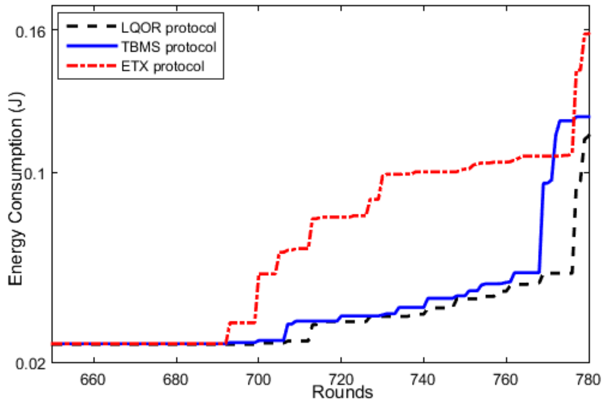

Fig. 8: Energy consumption (J).

IV. Conclusion

The energy usage of smart devices is one of the key issues in IoT architecture. Thus, it is important to not waste the energy with overheads and retransmission due to inefficient routing algorithms. In this paper, an energy efficient routing scheme has been proposed to enhance routing for a scalable WSNs that enables the IoT networks architecture. LQOR protocol is shown to provide high quality path by intelligent node selection based on the neighbouring nodes information. This reduces the overhead due to retransmission and the algorithm act as a load balancer significantly improving the overall energy usage and network lifetime. Simulation results confirmed the superior performance of our proposed scheme against other known schemes. Moreover, LQOR technique minimized the number of paths and total transmission distances by up to 16.9% and 1.8% respectively, thus, increasing the network lifetime.

The immediate future work is to implement the proposed protocol in an even larger area with increased number of nodes. We will also compare LQOR with other popular protocols illustrating the superiority of the scheme.

V. Acknowledgement

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