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Design of routing protocol for enhancing quality of service in wireless ad hoc and sensor network: LEQA

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ABSTRACT

Wireless sensor networks (WSNs) are now adopting mobile sensors due to their increased popularity in research and industry. To enhance WSNs' performance, mobility can be utilized to gather data. But, if the collector's route is fixed and movement is not manageable, current quality of service (QoS) strategies and protocols are ineffective in achieving timely data delivery while maintaining energy efficiency. In the real world, WSN networks use both actuator-actuator and sensor-actuator coordination. To conserve energy in communication tasks with heavy traffic and high volume, sensors/actuators can be relocated to desired locations. This study introduces a routing protocol that optimizes delivery latency and energy conservation in WSNs. The proposed latency, energy, and quality of service aware (LEQA) protocol uses a cooperative approach to track the sink and coordinate communication between sensors and actuators. Each sensor schedules its time division multiple access (TDMA) to improve QoS metrics such as low energy consumption, low latency, or packet loss. It also addresses sensor-actuator coordination and proposes a data communication protocol for efficient and fast communication with actuator nodes. This reduces energy consumption and minimizes latency.

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1. INTRODUCTION

Advancements in miniaturized integrated circuits (IC), low-power wireless communication, and micro-electro-mechanical systems (MEMS) have fueled the rapid development of wireless sensor networks (WSNs) [1]. Typically, it consists of small sensor nodes with limited computation power and memory; but equipped with sensors and actuators. WSN is a promising technology for a variety of system applications because of its advanced sensing/actuating, computation, and communication capabilities. Compared to wired technology, the WSN technology provides [2] flexible deployment of sensor nodes and saves a large extent of wiring costs. Besides, many process variables that have long been immeasurable in wired networks can now be easily measured, and temporal measurements can be easily carried out in WSN.

Wireless sensor and actuator network (WASNs) has several advantages: in agriculture, battlefield surveillance, home automation, precision animal control, networked robot, and environmental monitoring. It is an extension of WSNs [3]–[5]. Actuators communicate better than sensor nodes and are responsible for decision-making and responding to received data within the WSN area. To utilize the communication ability of actuator nodes, efficient coordination communication is necessary. These levels of coordination are sensor-sensor, sensor-actuator, and actuator-actuator [6]. Sensor-sensor coordination is needed to collect surveillance data. sensor-actuator coordination is needed to report and act on the data. Actuator-actuator coordination must also coordinate with each other to perform the necessary actions [7]. In general, WSN typically performs three operations: sensing events within the network, making decisions based on this data, and taking action accordingly. Note that coordination varies based on network architecture: semi-automated architecture (base station coordinates, manages, and monitors the overall network) and automated architecture (coordination is done without a central controller). In this work, the second approach (automated architecture) is employed because of its efficiency; the detected event is immediately sent to the actuator nodes, enabling faster response times.

In addition to network architecture, saving energy is a critical issue in WSNs. Several researches have been done to implement a protocol capable of reducing energy consumption thereby maximizing the network lifetime. In areas where a short delay event reaction is required, WSN can be used [8]. In such WSN networks, delivering detected data and meeting quality of service (QoS) requirements are essential for prompt action [9]–[13]. To ensure QoS requirements are met and routing decisions are not impacted, networks must optimize E2E delay and energy consumption.

Due to the heterogeneous and dynamic change of WSN networks, there have been several protocols proposed that cannot be directly applied in the context of WSNs. Some of the different researches that have been reviewed in the area of mobile routing solutions based on clustering and some relevant other approaches are discussed in this section. Vijayalakshmi and Rao [9] have proposed energy aware multicast clustering (EAMC) with increased QoS in mobile ad hoc networks (MANETs). They develop an energy-aware multicast cluster ad hoc on-demand distance vector (AODV) routing protocol to enhance the QoS of MANETs and obtained an increased QoS performance for the network system. Compared to the existing AODV and multicast ad hoc on-demand distance vector (MAODV) routing methods, the developed routing protocol enhances the E2E delay, energy usage, efficiency, packet delivery ratio (PDR), and minimizes the loss and overhead. To save energy and attain high QoS of the cluster member nodes, they use an efficient clustering algorithm. Cheng *et al.* [14] developed proposed efficient QoS-aware geographic opportunistic routing (EQGOR) in WSNs and use geographic opportunistic routing (GOR) to provide multi-constrained QoS WSNs. By doing so, they discovered that the current GOR protocol is unsuitable for providing QoS in WSNs. To provide QoS in WSN, the EQGOR algorithm uses the GOR protocol because of its computational delay. This algorithm/scheme balances multiple objectives well by considering the limited resources of sensor devices and having a low time complexity.

Wu *et al.* [5] have proposed delay-aware energy-efficient routing toward a path-fixed mobile sink in industrial WSNs. This protocol achieves a delay-aware energy-efficient routing in WSNs with a mobile sink that follows a fixed path. DERM uses location-based forwarding to allow nodes to efficiently relay packets to a destination region that can be accessed by the mobile sink within a specified delay. The authors introduced an energy-saving method for accurately calibrating the location of the sink, correcting any differences between its estimated and actual movements. Eventually, they found that routing the track ensured timely and dependable packet delivery while also maximizing energy efficiency based on speed and delay constraints.

Burgos *et al.* [15] introduced leader-based routing protocol for mobile WSNs. To optimize message delivery rates, the authors used leader elections to restructure the spanning tree based on local information about link quality. The protocol uses two sub-protocols, latency based routing (LBR1), and latency based routing (LBR2) for providing a good delivery rate and forwarding messages periodically respectively. Yahiaoui *et al.* [3] have suggested an energy-efficient and QoS-conscious routing protocol for wireless sensor and actuator networks. The authors developed a novel clustering mechanism that is based on their energy state and degree of connectivity. The authors achieved minimized delay and reduced energy consumption for reaching actuator nodes by utilizing sensor-actuator communication and an on-demand routing-based data communication protocol. Amgoth *et al.* [16] proposed an Energy-conscious routing algorithm for WSNs, which includes both clustering and routing phases. They showed that effective cluster-head (CH) organization into different levels can be achieved without any need for control message exchange during selection.

Zhu *et al.* [17] have proposed a tree-cluster-based data-gathering algorithm (TCBDGA) for industrial WSNs with a mobile sink. Cluster-based data gathering is created using a weight-based tree construction approach. To ease the load at rendezvous points (RPs) and sub-rendezvous points (SRPs), the authors proposed the adjusting method. As a result, TCBDGA balance the traffic load, prolong the network lifetime, reduce energy usage, and improve the hotspot problem. Kumar *et al.* [18] has proposed an algorithm for Cluster-based algorithm to track mobile sensors' positions. Three different cluster-based cooperative tracking methods were used to track position: one without a Kalman filter (KF), one with a KF, and one with a KF and inertial sensors. They found that the cooperative tracking approach improved accuracy and energy efficiency by about one-third compared to individual-based sampling in a fixed periodic global positioning system (GPS) sampling method. Velmani and Kaarthick [19] proposes an efficient data collection method for large mobile WSNs using a cluster-tree structure. They proposed the velocity energy-efficient and link-aware cluster-tree (VELCT) algorithm to create a successful network management architecture for WSNs based on mobility. In [20], [21], the QoS in optical networks and WSNs is studied but energy is not considered as a measuring metric. On the other hand, in [22]–[27], an intelligent-based routing protocol for WSNs is proposed and easured energy and delayare defined and measured as performance metrics. The obtained results in energy and latency are still not satisfactory for WSN applications.

Unlike in the research above, in this work, we are motivated to design and propose an energy and QoS-aware routing protocol in mobile WSNs that minimizes delay and energy usage for mobile nodes. The protocol organizes a protocol in clusters monitored by a CH and introduces a metric in the CH election process for accessing a candidate sensor. We use distance metrics to determine the distance between the candidate node and the actuators. By prioritizing sensor nodes with strong energy capacity and abundant connectivity, we obtained an improved reliability value of the network and reduced energy consumption. The proposed routing protocol is capable of reaching the actuator nodes with minimum delay, reduced energy usage, and used a modified on-demand routing-based data communication method. Furthermore, using the cooperative tracking method the protocol tracks mobile actuators by exchanging the location of their neighbor’s actuator’s location.

Moving from this background and literatures, the aim of this article is to design a routing protocol for enhancing QoS in mobile WASN. By employing an on-demand routing technique offers an effective gain interms of end to end (E2E) latency and energy usage and actuator nodes for detecting events and senses information such as, temperature, humidity, and motion detection. These nodes transmit information directly to the base station or via other nodes, this article proposed an energy and QoS aware routing protocol.

2. METHOD/SYSTEM MODELLING

The proposed design focus on three methodological phases: literature works, design and analysis, performance evaluation, and implementation tools. The first phase is to collect secondary data from previously published studies related to cluster-based routing (for both static and mobile sensors), energy-efficient and QoS-aware routing, and tracking mobile nodes. The second phase is designing, implementing, evaluating, and analyzing a network model using the known routing protocols and analysis observed by the third phase focused on performance evaluation; the fourth phase describes the implementation tools for performance evaluation as shown in Figure 1.

Figure 2 presents the network architecture employed to test the performance of the designed routing protocol. It consists of sensor and actuator nodes linked wirelessly via ad hoc technology. In this network, actuator nodes are distributed evenly to predict uniformly across the surveillance area. It is also assumed that the actuator nodes and sensor nodes communicate smoothly. Like mobile wireless sensor networks (MWSN), the sensors are mobile, small in size, and devices with limited resources are used to monitor the environment and report events to the actuator nodes. This research has the following assumptions:

- Actuator nodes might be mobile devices
- Actuators have limitations in their resource capabilities.
- Actuators can transmit signals over longer distances than sensor nodes.
- Sensor nodes are grouped into clusters, with one sensor node chosen as the CH for each cluster.

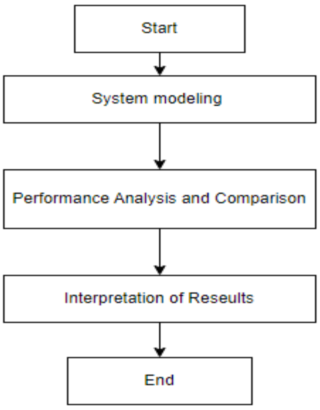

Figure 1. Methodology flow chart

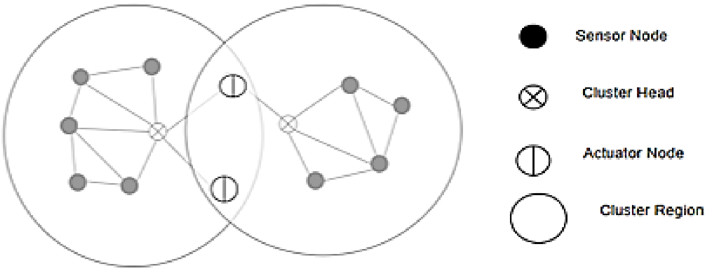

Figure 2. Node deployment

2.1. Flow chart of the proposed routing protocol

As it is shown in Figure 2, the network model which has two CHs in different regions is illustrated. For this network scenario, Figure 3 shows the flow chart or sequence figure of the newly proposed protocol behaves in the network, i.e. when the CH is in the range of the neighbor CH (NCH), the cross-section between the regions can aggregate their data. At the same time, when CH finishes the energy, it will notify the members of its weight to choose a new CH. The proposed protocol is a model of the network with a graph G (V, E), where network nodes are denoted as V and the communication links are represented by E. When a sensor node triggers an event, the CH should find the best route to the actuator node A. The proposed algorithm follows an on-demand routing method. The protocol only establishes routing paths to the actuator node A when the CH needs to send an alert. It establishes routing paths based on the energy and communication delay of the intermediate sensor nodes. To find the routing paths to actuator node A, the CH starts a route recovery process by creating a route request message (RREQ) packet. The intermediate sensor nodes forward the latter until it reaches the actuator node A. Each intermediate sensor node includes information about transmission delay and the energy status in the route replay (RREP) packet. The CH may receive multiple RREP packets due to the presence of more than one intermediate sensor node.

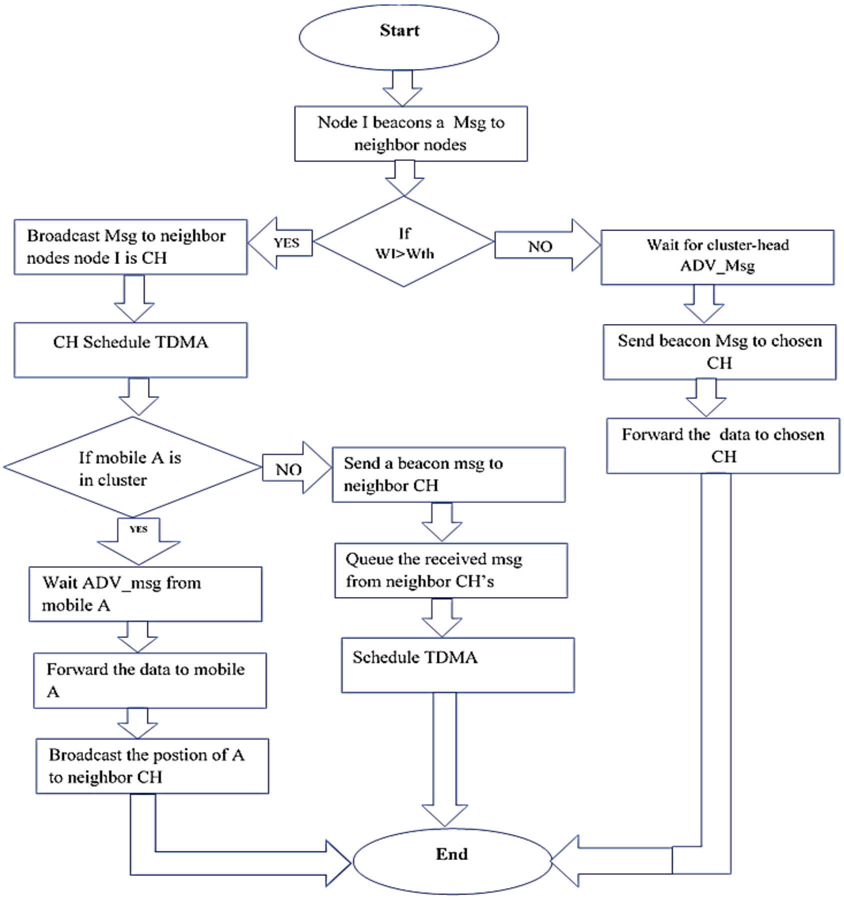

Figure 3. Flow chart of the proposed protocol

In this scenario, the CH can determine the optimal routing path by calculating the following routing paths:

$$P(ch, Nch, A) = \frac{max(p1(ch, Nch, A), p2(ch, Nch, A) \dots\dots\dots\dots..pn(ch, Nch, A))}{\Delta pi(ch, Nch, A)}$$

where P_n represents the available routing paths from CH to A, N_{ch} represents the neighbor cluster heads, $\Delta pi(ch, Nch, A)$ is the delay during the routing g path as shown in Figure 4.

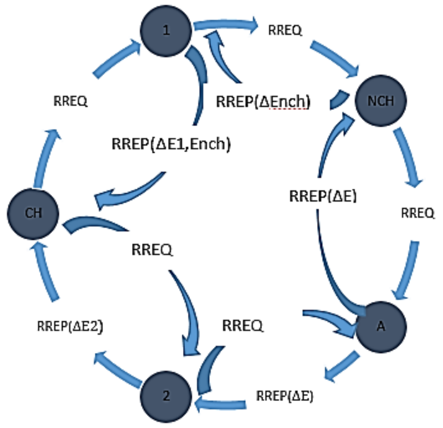

Figure 4. How RREQ and RREP packets are created (E_i represents the residual energy of node I and Δ the communication delay)

3. RESULTS AND DISCUSSIONS

3.1. Simulation variables

Table 1 shows the set of simulation variables that have been used during simulation period. By varying the number of sensor nodes and number of actuators. With uniform actuator node deployment and random sensor deployment, residual energy and average communication delay are analyzed.

Table 1. Simulation parameters

Simulation variables	Values
Chanel type	Wireless
Network interface type	Phy wireless phy/IEEE 802.15.4
MAC type	MAC/802.15.4 XMAC
Number of sensor node	10 to 60
Number of Actuators	2 to 10
Routing protocol	AODV
Packet size	96 byte
Sensor nodes deployment	Random
Actuator nodes deployment	Uniform
Simulation area	800×800 m^2
Sensor node radio range	250 m
Actuator node radio range	400 m
Radio propagation model	Propagation/two-ray ground
The initial energy of the sensor node	1J
The initial energy of the actuator	4J
Frequency of CH refresh	5 min
Network simulator	OMNeT++, inet framework
User-interface	Qtenv

3.2. Simulation results

Once each region selects its cluster head it will wait only for some time because of source limitations like power. As time t progresses, a forwarding candidate may observe an increase in the number of neighbors. To schedule its time division multiple access (TDMA) mode, the duty cycle is adjusted accordingly. However, if the number of neighbors becomes too high (N_{chi}), the resulting energy consumption (E) decreases. This causes the forwarding candidate to remain in sleep mode for a longer period of time. The residual energy of the system is analyzed based on this behavior, as shown in the following figures. This metric calculates the percentage of energy used by a node in relation to its initial energy. By measuring the initial and final energy levels of the node at the end of the simulation, the energy consumed can be calculated as a percentage of the initial energy. The average energy consumption of all nodes in a scenario can be determined by calculating the average of their individual energy consumption percentages.

$$Average\ Energy\ Consumed\ =\frac{Sum\ of\ Percent\ Energy\ Consumed\ by\ All\ Nodes}{Number\ of\ Nodes}$$

3.2.1. Delay of each cluster heads

In Figure 5 the communication delays in the function of the network size actuator node are presented. The communication delay of our protocol, latency, energy, and quality of service aware (LEQA) provides a lower communication delay compared to previous works such as enhanced resource and information control (ENRICO) and QoS-aware and heterogeneously clustered routing (QHCR). This is because LEQA uses the AODV routing protocol to dynamically choose a route path rather than a static and fixed route path.

Figure 6 shows that the reporting event delays versus the event number. Our approach's reporting event delay is lower than the previous works. To minimize reporting event delay, our approach uses TDMA scheduling for communicating with actuator, unlike others.

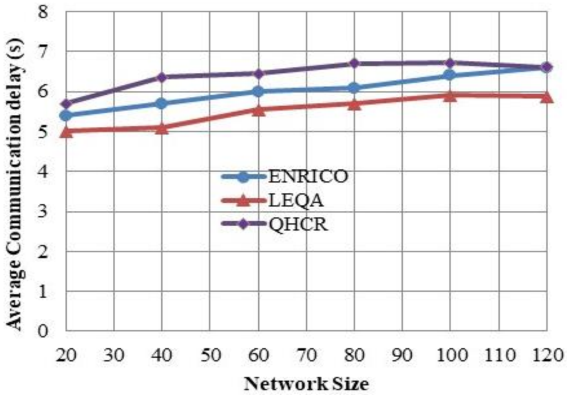

Figure 5. Communication delay versus the network size with 6 actuator nodes

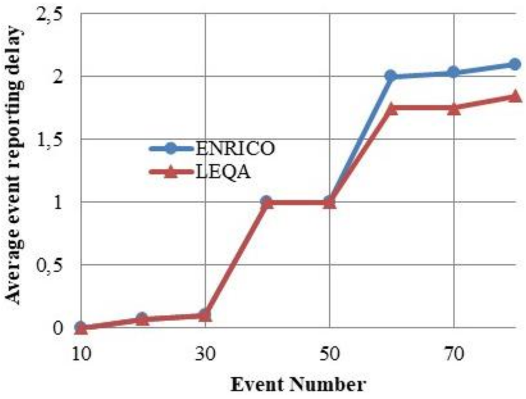

Figure 6. Reporting event delay versus the event number

3.2.2. Average residual energy of sensor nodes

In the proposed approach, clustering is performed during the initialization phase and sensors are deployed randomly. As both sensors and actuators have limited energy, it is crucial to use it efficiently. To evaluate the energy consumption of our approach, we compared it to an energy-efficient and QoS-aware routing protocol for wireless sensor and actuator networks (ENRICO's work), as illustrated in Figure 7.

Figure 7 shows that the average leftover energy of sensor nodes of LEQA is greater in comparison with to the previous approach. Unlike ENRICO's work, the proposed protocol uses the cooperative method to choose CH. The cross-section between the graphs shows LEQA node mobility and CH selection during different time intervals. In Figure 8, the Average leftover energy of actuator nodes versus the event number is illustrated. As LEQA employs TDMA for communicating CH with Actuator, it shows minimized energy consumption as the event number increases. This shows that our protocol, LEQA, outperforms best with regard to energy than Enrico's work.

Figure 9 presents a plot of Energy consumption verus the network size. In our approach, we obtained a lower average leftover energy of actuators than ENRICO's work (our reference). This is because CH selection in LEQA is based on queue weight and leftover energy of sensors in the field. The comparison of network energy consumption between ENRICO (42.04%) and our approach is 38.53%. Therefore, our approach minimizes energy consumption by 3.506%.

Figure 10 displays the energy consumption of actuator nodes as a function of the number of actuators (with 50 sensor nodes and 30 events). Our approach demonstrated superior results as the network size increased. The proposed protocol can optimize energy consumption by dynamically selecting a routing path in the event of a link breakage.

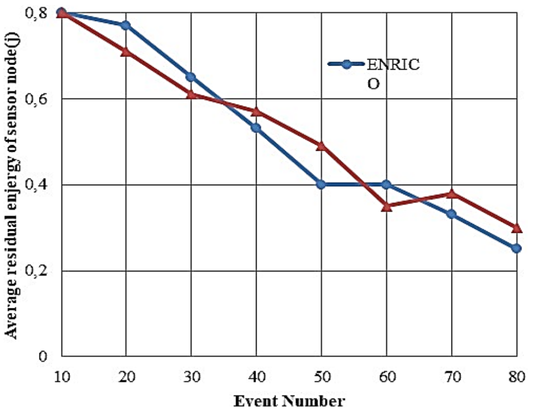

Figure 7. Average residual energy of sensor nodes in the function of the event number

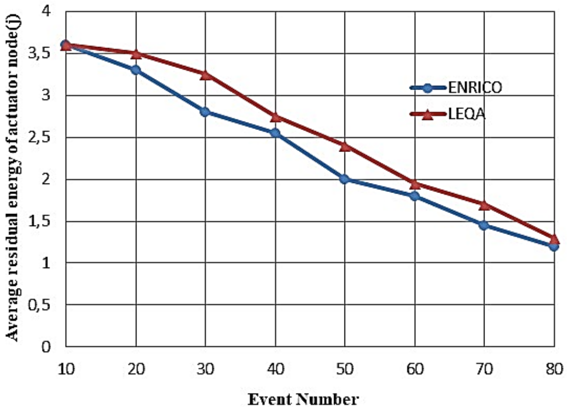

Figure 8. Average leftover energy of actuator nodes versus the event number (6 actuators)

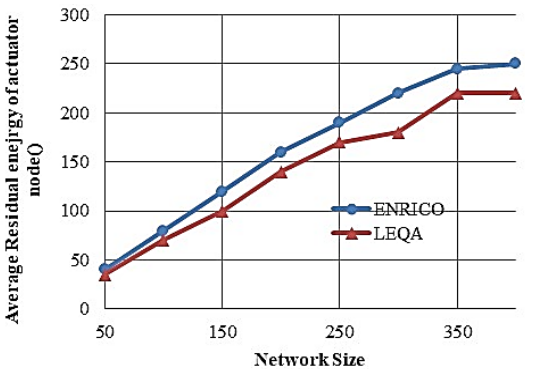

Figure 9. Energy consumption versus network size under 70 events

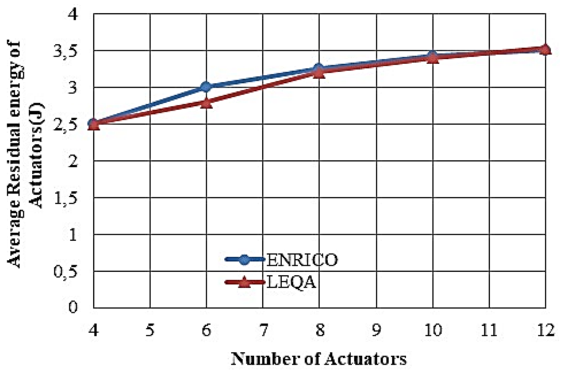

Figure 10. Energy consumption of actuator nodes versus of the actuator number (50 sensor nodes, 30 events)

The energy consumption of sensor nodes with six actuator nodes is shown as a function of network size in Figure 11. Our approach outperformed ENRICO's work, even as the number of actuator nodes increased. The method utilizes coordinating and scheduling TDMA to facilitate communication with the actuator.

Finally, Figure 12 describes tracking the position of the mobile actuator of LEQA and cloud-based trust management scheme (CBTMS). Since LEQA uses TDMA and mobile actuator advertisement, the mean position error of all nodes is lower than that of the CBTMS approach. In addition, our approach employs local cooperative method to get the target location.

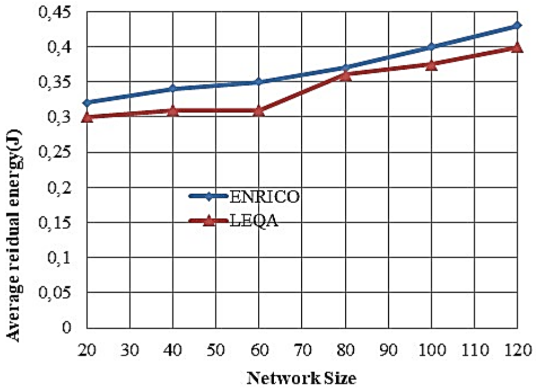

Figure 11. Energy consumption of sensor nodes in the function of the network size with 6 actuator nodes

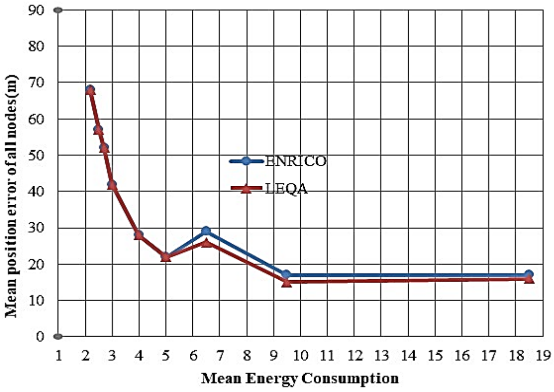

Figure 12. Tracking the position of the mobile actuator

4. CONCLUSION

WSNs face the challenge of balancing data delivery and energy preservation. To address this issue, we propose a novel energy-efficient and QoS-aware routing algorithm for mobile WSNs called LEQA. The algorithm comprises clustering, routing, and tracking approaches that consider the weight in clustering, the number of nodes in the communication range, and the cooperative method between neighbor clusters. Our approach enhances energy consumption, data delivery, throughput, and neighbor cache. In the clustering approach, we consider the weight of each node and compare it with its neighbor nodes' weight to select CH. The degree of connectivity or a node with more neighbors is taken into account. Additionally, since each CH sends data to the actuator according to their scheduled TDMA, the delivery of the data is guaranteed. We also propose an AODV routing protocol for dynamic network changes and a lower delay rate in the scenario.

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