EARQ: Energy Aware Routing Protocol for Real-Time and Reliable Communication in Wireless Industrial Sensor Networks

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Abstract: the majority of techniques for wireless sensor networks can be applied to the wireless industrial sensor networks. Though, for industrial applications of wireless industrial sensor networks, new requirements for example real-time, reliable delivery need to be considered. In this paper, we propose EAQR, which is a novel routing protocol for wireless industrial sensor networks. It provides real-time and reliable delivery of a packet, while considering energy awareness. In EAQR, a node estimates the cost of energy, delay and reliability of a path to the sink node; it’s based on only information from neighboring nodes. Next, it calculates the probability of selecting a path and using for the estimates. When packet forwarding is required, in that time it randomly selects the next node. A lower energy cost of path is likely to be selected, why because the probability is inversely proportional to the energy cost to the sink node. To accomplish real-time delivery, it only paths that may deliver to a packet in time are selected. To achieve dependability, it may send a redundant packet via an alternate path, but if it is only source of a packet. Experimental results show that EAQR is suitable for industrial applications, due to its capability for efficient energy, real-time and reliable communications.

Keywords: Area-Efficient, CSLA, Low Power, Real-Time and Reliable Communication, Wireless Industrial Sensor Networks.

I. INTRODUCTION

Wireless industrial sensor networks (WISNs) are used to collect data from a machine equipped with sensor nodes, and forward data to the sink node; they are generally used for industrial control applications. The sink node is connected to a control system that obtains data via the sink node, and controls actuators in a machine, or alerts users as a result of data analysis. Wireless industrial sensor networks can provide lower cost cables, and easy setup and maintenance [1] for existing industrial applications. WISNs are useful for factory automation involving a variety of applications, for example an industrial process control predictive maintenance of a machine [2], industrial linear position. Machine vision is an application of computer vision for industrial process control. Machine vision involves input/output devices and control networks, which can be replaced with WISNs. Machine vision can improve the quality of manufacturing, by searching for product defects using information from WISNs. Predictive maintenance can improve productivity by monitoring and assessing the health status of a piece of equipment in a machine. Industrial linear position is an industrial application for measuring displacements of moving parts. In WISNs, it is essential to consider new QoS requirements, for example real-time, reliable communication [1]. In WISNs, sensing data from sensor nodes must be transmitted to the sink, reliably and in time. Delayed data may cause industrial applications to malfunction, because the sensing data is analyzed and appropriate commands are sent to the actuator of a machine. Machine vision for industrial process is control to uses a multimedia stream, which is more affected by a packet loss than scalar physical phenomena. A delayed packet may be useless, and it is difficult to obtain meaningful information from decoding packets if the rate of packet loss exceeds a threshold. Soft real-time communications are acceptable in WISNs, because of fault tolerance, which is one of the major advantages of WISNs. Though some packets are lost or delayed, others may be transmitted continuously, or transmitted via another path. Applications such as machine vision require soft real-time Communications for the multimedia stream, where a slight delay of packet loss is tolerable.

Routing protocols for Wireless industrial sensor networks must be carefully designed to consider resource constraints such as low processing power, small memory and limited energy of sensor nodes [3]. In addition, WISNs must be scalable and able to tolerate dynamic network changes. They were range from tens to thousands of sensor nodes. So, the complexity of the routing algorithm must be independent of the size of the networks or the number of sensor nodes. They would be impractical if memory usage increases as the number of nodes increases. New nodes
may be newly deployed or disappear, due to malfunctions. Therefore, routing algorithms must adapt to dynamic network changes. WISNs may use routing protocol for wireless mobile ad-hoc networks or wireless sensor networks (WSNs), because they have similar wireless networks characteristics. In several studies real-time, reliable communication has been studied for wireless mobile ad-hoc networks. However, there were problems in applying these studies to WISNs, because the scalability of sensor nodes was not considered. There have been studies about real-time, reliable communication in WSNs [4]. Most of these studies do not provide simultaneous real-time, reliable and energy aware communication. The aforementioned WISNs require simultaneous real-time, reliable and energy aware communication. Then, it is necessary to design a routing protocol that can provide real-time, reliable communication and energy consciousness in WISNs.

In this paper we propose EAQR, which is designed to achieve the aforementioned requirements in WISNs. It provides real-time, reliable delivery of a packet, while considering energy. Especially, EAQR can set the packet reliability. I Redundant packets can be used to prevent packet loss in real-time communications. However, the number of packets in networks increases, due to redundant packets. Due to the increased number of packets, there can be congestion or increased energy expenditure. Therefore, setting the reliability of a packet is essential, so that the user can achieve a trade-off between energy and reliability. EAQR estimates the expected values of the energy cost, delay and reliability of a path to the sink node. These values are computed using only information from neighboring nodes. Based on these values, EAQR selects a path that requires low energy, low delay and provides high reliability. For an even distribution of energy expenditure, sometimes EAQR selects a non-optimal path in terms of energy expenditure, but can it still deliver a packet in time. This paper provides a simple approximation of the minimum delay [6]. The remainder of the paper is organized as follows. Section II describes the proposed routing protocol, EAQR. Section III presents the performance of EAQR compared to the previous protocols. In Section IV we describe simulation results. Lastly, concluding remarks are provided in Section V.

II. PROPOSED ROUTING PROTOCOL

EAQR is a proactive routing protocol that aims to maintain an ongoing routing table. As in extra kinds of proactive routing, EAQR constructs and preserve a routing table with information from neighboring nodes. A beacon message is used to exchange information related to routing among neighboring nodes. The real path is decided while transmitting a packet. There are two types of messages: beacon messages and data packets. A beacon message is exchanged among neighboring nodes to construct and maintain a routing table. Upon receiving a beacon message, a routing table is updated by calculating expected values of energy cost, delay and reliability. When a path to the sink node becomes known to a node, the node begins to send a periodic beacon message. The source node sends data packets to the sink after constructing the routing table. Every intermediate node forwards a data packet to a neighboring node that can deliver it in time to the packet. A neighboring node for forwarding a packet is selected based on the expected delay and probability. This is inversely proportional to the expected energy cost of neighboring nodes. Then, a path that may expend less energy than other paths is most likely to be selected. To ensure reliable packet delivery, if the predictable reliability of the selected node does not satisfy the required reliability, the source node selects an extra neighboring node to forward the packet.

A. Beacon Message and Routing Table

Each node exchanges a beacon message to construct and maintain a routing table of a node. A beacon message contains expected values such as energy cost (Ci), time delay (Ti), reliability (Ri), and residual energy (Bi) of a node. Ci is the expected energy cost of sending a packet from node i to the sink node. It is the expected time of sending a packet from node to the sink node. Ri is the predictable reliability of sending a packet from node i to the sink node. The reliability is the probability of sending a packet to the sink node without error. Csink = 0, Tsink = 0 and Rsink = 0 at the sink node and the expected values of the sink node are constant [5]. The beacon message also contains the position of node i. EAQR assumes that every node knows its own position and that of the sink node. The information can be obtained by GPS or localization protocols for estimating the location of a node [7].

The predictable values of a node may change as the residual energy of a node decreases and the state of the network changes dynamically. Formerly a node obtains a path to the sink node; it broadcasts a periodic beacon message to its neighboring nodes, to inform them of the change of predictable values. Because the expected values of the sink node are constant, the sink node only sends a beacon message while initiating network setup and receiving an empty beacon message. An empty beacon message is a beacon message that contains nothing. When a node receives an empty beacon message from another node, it responds to the node with a beacon message. A new node collects some routing information by broadcasting empty beacon messages to its neighboring nodes. It makes its own routing table with beacon messages from its neighboring nodes. When a node receives a beacon message from a neighboring node, it adds only the neighboring node to the routing table if the neighboring node is closer to the sink node than it is. If the neighboring node i is
already in the routing table, it only updates the expected values of the neighboring node. Fig.1 shows an example of neighboring nodes in the routing tables of node i. Nodes in the area are neighboring nodes of node i. They can communicate with node via a wireless channel. Area may not be a perfect circle, because each node may have a different wireless communication range or there may be things interfering with wireless communication, for example the machine shown in the figure. In a wireless industrial environment, this kind of noise source must be considered. Area B is a circle at which the center is the sink node and the radius is the distance between node i and the sink node. Nodes in area B are closer to the sink node than node I because node is at the edge of area B. The neighboring nodes located at the intersection of areas A and B (shaded area of the figure) can be added to the routing table of node i. When the expected values of neighboring nodes are updated by a beacon message, the routing probability \( P_{i,k} \) is updated \( T_i, C_i \) and \( R_i \), and are recalculated. When node I receive a beacon message from the neighboring node j, node updates these expected values as follows [5]. The beacon message contains as \( C_j, T_j, R_j \) and \( B_j \)

\[
C_{i,j} = C_j + E_{i,j} \\
T_{i,j} = T_j + H_{i,j} \\
R_{i,j} = R_j + L_{i,j}
\]  

Where, \( C_j \) is the expected energy cost of sending a packet from node i to the sink node via node j. \( T_{i,j} \) is the expected late time of sending a packet from node i to the sink node via node j. \( R_{i,j} \) is the expected reliability of sending a packet from node i to the sink node via node j. \( E_{i,j}, H_{i,j} \) & \( L_{i,j} \) are the energy cost, average time and link strength single hop to communication between node and node i,j, respectively. For node k in RT—which is the routing table of node i.

\[
P_{i,k} = \frac{1/C_{i,k}}{\sum_{m \in RT} C_{i,m}}
\]  

(2)

\( P_{i,k} \) is the probability that node selects node to forward a packet. Therefore, a neighboring node with a lower energy cost is more likely to be selected. Here, the expected values of node can be obtained as follows:

\[
C_i = \sum_{k \in RT} P_{i,k} C_{i,k}
\]  

(3)

\[
T_i = \frac{\sum_{k \in RT} P_{i,k} T_{i,k}}{\sum_{k \in RT} P_{i,k}}
\]  

(4)

\[
R_i = \frac{\sum_{k \in RT} P_{i,k} R_{i,k}}{\sum_{k \in RT} P_{i,k}}
\]  

(5)

\[
P_i' = \frac{1/C_i}{\sum_{m \in RT} C_{i,m}}
\]  

(6)

Fig. 2 presents a graphical example of predictable values. The nodes in the region indicated by the dotted line are neighboring nodes in the routing table of node i. Each neighboring node \((k,j,l)\) and \(m\) has its own expected values for sending a packet to the sink node.

B. Node Selection for Forwarding a Packet

When a node finds a path to the sink node, a data packet is ready, and a sensor node begins to send data packets received from another node, or its own data packets obtained from sensing. The deadline and dependability of a
packet may be predefined by user or determined by nodes at every transmission. The deadline is a relation deadline, which is the tolerable late of delivering a data packet to the sink node. The reliability, included in a packet is the desired dependability, which is between zero and one means that no degree of reliability is required, whereas means that a high degree of dependability is required. The laxity, which indicates the residual time until the deadline, it is embedded in a data packet and recalculated at every node along a path to the sink node. EAQR selects the next node to advance a packet, based on the laxity of a packet and the expected values of neighboring nodes [9]. A path to the sink node is constructed during packet transmission. A node—including the source node—selects next node, according to the rules as follows.

- Select nodes in the routing table, it can deliver a packet within the required deadline.
- Calculate the probability $P_{i,j}$ based on the $R'T'$. For every node $j$ in $RT'$

$$P'_{i,j} = \frac{1/C_{i,j}}{\sum_{k \in R'T'} 1/C_{i,k}} \quad (7)$$

- Arbitrarily select the next node by the probability $P'$ [5]. If a source node $i$ and selected node $Rj$ Is less than the required reliability $R$, randomly select one additional next node by the probability $P'$.

The selection algorithm based on probability prevents energy loss of nodes on the optimal path with the least energy cost, by distributing the load to other nodes on a non-optimal path. A maximum of two packets are sent to achieve dependability, according to the third rule. This is because the algorithm is simple and if there are more than two paths this may result in congestion of networks, due to too many redundant packets [7].

C. Considerations for Selecting the Deadline

The packet delay generally depends on the number of hops to the sink node. In another words, the density and size of the network affects the packet delay. A deadline selected at arbitrary without considering these network characteristics endangers applications of WISNs. Thus, the density and size of the network must be considered while selecting a deadline. In this section, we describe the resources to select an appropriate deadline, given the density and the size of the network. When sensor nodes are organized at a fixed interval, as in the expected number of hops to the sink node depends on the radio range and the distance to the sink node. If the aforementioned conditions are met, sensor nodes in two adjacent regions can communicate with each other. If the maximum width of the region is achieved, the minimum no of hops to the sink node can also be obtained.

III. PERFORMANCE EVALUATION

GloMoSim [8] was used to evaluate the performance of EAQR. This is a very fast, effective, discrete-event simulator for simulating wireless communications. It has thorough a propagation model, radio and MAC layers. In this section, Table I describes the detailed simulation parameters. In this section, we used the two-ray path loss model for the radio propagation model in the simulations. The two-ray model thinks both the direct path and the ground reflection path. In this simulation, we used the signal-to-noise ratio threshold (SNRT) model for the signal reception model. If signal-to-noise ratio (SNR) of a packet exceeds the threshold, it receives the packet of error-free. Otherwise, the packet is dropped [8]. We used IEEE 802.11 DCF for the MAC layer protocol. EAQR and other protocols compared in the paper are table-driven routing protocols for static wireless networks such as wireless industrial sensor networks. The relative performance of these protocols for such networks is largely independent of MAC layer protocols such as CSMA, MACA, and 802.11 DCF. Therefore, simulation with a single common MAC protocol is sufficient for the performance comparison of the routing protocols in these networks. Every sensor node sent data to the sink node at an interval of one second. Each node sent a beacon message at an interval of 10 s. In EAQR and other protocols [10].

- Packet delivery ratio: The ratio of the more packets received and the number of packets expected to receive.
- Normalized control overhead: The total number of control message transmissions divided by the total number of received data packets. Every forward of the control message was counted as one transmission.
- Normalized no of data packet transmission overhead: The ratio of the total number of normalized data packet transmissions and the number of received data packets.
- Joining delay: The average interval time between a member joining a group and its first receiving of the data packet from that group.
- Multicast efficiency: It defined as the number of data packets delivered to multicast receivers over the number of total data packets forwarded. Higher value implies to better performance.

Multicast Efficiency= the total received packets / total forwarded packets \( (8) \)

IV. SIMULATION RESULTS

A. Average Power Conservation vs Time

The performance of average power conservation of EAQR is shown in the graph. EAQR is the modified on-demand multicast routing protocol and SEAQR is the secure on-demand multicast routing protocol. Compared to
EAQR and MSEAQR, SEAQR is more secure and will give the more data delivery and less delay. The moving speed of nodes is uniformly set between the minimum and maximum speed values which are set as 1 m/s and 20 m/s, respectively. IEEE 802.11b was used as the MAC layer protocol. Fig 3 shows the simulation results of Average power conservation Vs Time.

![Average power conservation Vs Time](image1)

**Fig. 3:** Average power conservation Vs Time

### B. Speed vs Delivery Ratio

In EAQR, the mesh structure is built on the source’s demand, and a source sends out a JOIN QUERY message periodically to refresh the mesh structure. If the nodes are want to join a group, they need to wait for until the next mesh refreshing period. The refreshing period interval is set as 3 seconds. Fig.4 shows the simulation results for Speed and Delivery ratio.

![Speed vs Delivery ratio](image2)

**Fig.4:** Speed vs Delivery ratio

### C. Byte Sent Byte Delivered vs Speed

Using EAQR we can receive the more number of data. It is difficult and challenging for a multicast routing protocol to maintain a good performance in the presence of node mobility in an ad-hoc network. In this section, we evaluate the protocol performance by varying maximum moving speed from 5 to 40 m/sec. Fig.5 shows simulation results of Byte sent byte delivered Vs Speed.

![Byte sent Byte delivered vs Speed](image3)

**Fig.5:** Byte sent Byte delivered vs Speed

### D. Time vs Throughput

By varying the time period from 0 to 50 m/s and we can analyse the through put. As the time period increases the through put also increases in EAQR. But compared to EAR, EAQR has highest through put. It delivers the 95% of data send by the source. Fig 6 shows the simulation results of Time Vs Throughput.

![Time vs Throughput](image4)

**Fig.6:** Time vs Throughput
V. CONCLUSION
This paper proposed EAQR, an energy aware routing protocol for real-time, reliable communication in WISNs. EAQR provides real-time communication without compromising the energy awareness of the existing energy aware routing protocol (EARP). It selects a path that used less energy than others, among paths that deliver to a packet in time. Sometimes, it selects a path that uses more energy than the optimal path, because this path is selected at random manner, according to a probability. This enables even distribution of energy expenditure to sensor nodes. In addition, EAQR provides efficient and reliable communication, because it is only sends to a redundant packet via an alternate path if the reliability of a path is less than a predefined value. The deadline, which is the maximum bearable packet delay, it must be carefully selected. The deadline must be longer than the minimum network delay. This paper predictable the minimum delay, to select a deadline given the thickness of sensor nodes and radio range. In this section, simulation results showed that EAQR performs better than existing QoS routing protocols, in terms of dipping the number of packets that missed deadlines, while considering the energy awareness.

VI. REFERENCES


