

Research Article

Enhanced EARQ Protocol for Reliable Routing in Wireless Sensor Networks

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Abstract: Wireless Industrial Sensor Network (WISN) is the heart of automation and control in industrial monitoring. Live updates about situations at hostile areas of the industry are reported to a base station frequently to enhance harmless functioning of the network. EARQ was proposed to enhance the routing operations for wireless industrial sensor networks. It provides real-time, reliable delivery of a packet, while considering energy awareness. In EARQ, a node estimates the energy cost, delay and reliability of a path to the sink node, based only on information from neighboring nodes. The expected energy cost measurement does not provide accuracy; hence the relative energy cost is measured to enhance the lifetime of the WISN while also enhancing the routing reliability in the Enhanced EARQ (EEARQ) protocol proposed in this study. Simulations in the network simulator are used to justify the proof of the enhancement.

Keywords: EARQ, energy awareness, enhanced EARQ, reliability, wireless industrial sensor network

INTRODUCTION

Wireless Industrial Sensor Networks are networks Industries require incessant monitoring and control to facilitate sound operation at various tactical environmental conditions. Some of the WISN applications include, process monitoring and control, process data such as pressure, humidity, temperature, flow, level, viscosity, density and vibration intensity measurements can be collected through sensing units and transferred wirelessly to a control system for operation and management (Zhao, 2011). Figure 1 shows an example Wireless Industrial Sensor Network.

The flow of information from the sensor nodes to the base station needs to be reliable, rapid and less energy consuming. By incorporating these features into a WISN, it is possible to improve the network lifetime and efficiency to a good extent. The main challenges involved in the design of a reliable protocol for WISN are:

- The computation time of the route selection is to be kept as low as possible as the delay may have a great impact on preventing harmful consequences.
- Confrontation of the dynamically changing link statistics is intricate.
- Energy consumption of the nodes is to be kept very low.

Having analyzed the above issues Heo *et al.* (2009) developed a protocol called EARQ: Energy Aware

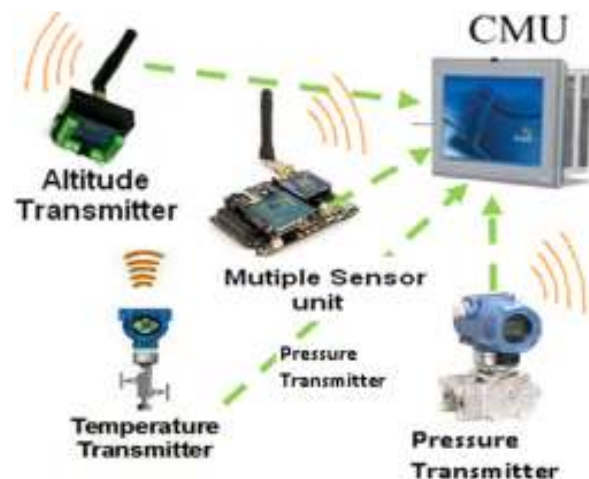


Fig. 1: An example WISN

Routing for Real-Time and Reliable Communication in Wireless Industrial Sensor Networks. The protocol estimates the expected energy cost and delays along with the reliability of the nodes successively that form the path to the base station. The technique is advantageous in many ways; however, has a design weakness. The expected energy cost does not provide accuracy as it is probabilistic in nature.

The enhancement proposed in this method involves the realistic measurement of energy consumption with respect to a node's current expenditure rate, which is the main contribution of this study.

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LITERATURE REVIEW

The evolution of the EARQ protocol is discussed briefly. The first standard energy efficient protocol is Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol was proposed by Heinzelman *et al.* (2000) for clustering in wireless sensor network. Heo *et al.* (2009), take the view that using lowest energy paths may not be optimal from the point of view of network lifetime and long-term connectivity always. To optimize these measures, Energy Aware Routing for Low Energy Ad Hoc Sensor Networks, was proposed which uses sub-optimal paths occasionally to provide substantial gains.

EAR-RT: Energy aware routing with real-time guarantee for wireless sensor networks was then proposed by Heo *et al.* (2006), to minimize the delay occurring during the computation process of the network so that there is no tradeoff between the energy and the delay.

EARQ, also proposed by Heo *et al.* (2009) is a kind of proactive routing protocol that aims to maintain an ongoing routing table. An information table is constructed and maintained at every node using which routing is performed. A beacon message is used to exchange information related to routing among neighboring nodes. The actual path is decided while transmitting a packet. Compared to EAR-RT, EARQ neither requires a separate setup phase, nor utilizes overhearing characteristics of wireless networks. In addition, EARQ provides reliable delivery of a packet, as well as real-time delivery. EARQ also requires MAC support.

The beacon message consists of three main parameters in EARQ: energy Cost (C_{ij}), Time delay (T_{ij}) and Reliability (R_{ij}):

$$C_{i,j} = C_j + E_{ij} \tag{1}$$

$$T_{i,j} = T_j + H_{ij} \tag{2}$$

$$R_{i,j} = R_j \cdot L_{ij} \tag{3}$$

where,

E_{ij} = The energy cost required for transmitting data from i to j

H_{ij} = The average time for single hop communication from i to j

L_{ij} = The link strength between i and j

C_j, T_j and R_j = The individual energy cost, time and reliability of the next hop j , respectively

The limitation of the EARQ technique is that the nodes calculate the expected Energy costs (E_{ij}) which may not always be accurate.

Some other related works are Highly-resilient, energy-efficient multipath routing in wireless sensor networks (Ganesan *et al.*, 2001). Energy aware routing for low energy ad hoc sensor networks (Shah and

Rabaey, 2002) and Energy efficient routing in wireless sensor networks (Schurgers and Srivastava, 2001).

PROPOSED ENHANCEMENT

The main objective of this study is to provide a realistic method to evaluate the energy cost in order to be updated in the table at every node. Since EARQ is a proactive method, the information table maintained at every node is supposed to store the C_{ij}, T_{ij} and R_{ij} values as referred in Eq. (1), (2) and (3), respectively.

To provide a realistic way of evaluating the energy, we propose a realistic energy cost RC_{ij} value that not only computes the energy required to transmit to the sink but also uses the previous energy consumption when data was sent via that node as in Eq. (4):

$$RC_{ij} = C_j + \frac{(W_j + E_{ij})}{2} \tag{4}$$

where, W_j is the amount of energy used for communication via j in the previous communications.

W_j value is defined as the total energy per packet per unit time of the most recent communication at the node j :

$$W_j = \frac{B_{j,t} - B_{j,t+1}}{k} \tag{5}$$

where, $B_{j,t}$ and $B_{j,t+1}$ are the residual energy values of the node j at the instant of time t and $t+1$ respectively;

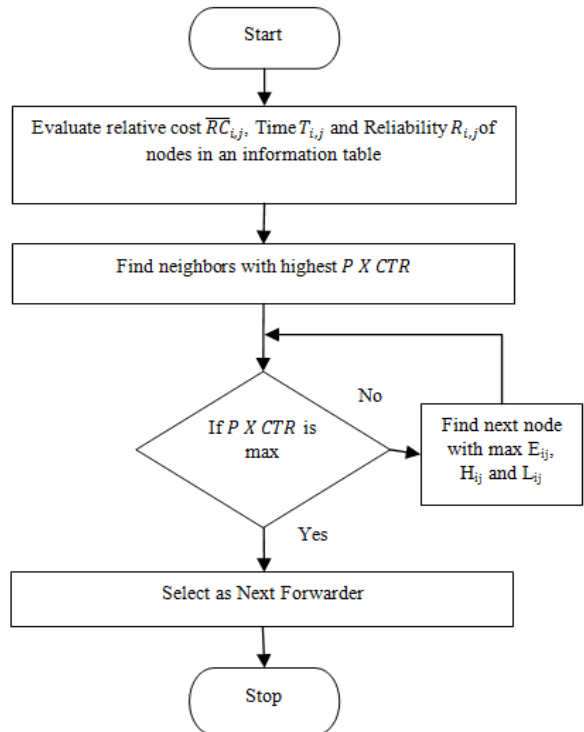


Fig. 2: Working flow of EEARQ

and k is the data rate at which communication takes place. This value is averaged with the computational energy E_{ij} for the realistic energy cost estimation. These values are then used to estimate the energy cost values of a node given by Eq. (6):

$$P \times CTR = P \times \begin{pmatrix} \overline{RC}_{i,k} & \overline{T}_{i,k} & \overline{R}_{i,k} \\ \overline{RC}_{i,j} & \overline{T}_{i,j} & \overline{R}_{i,j} \\ \overline{RC}_{i,l} & \overline{T}_{i,l} & \overline{R}_{i,l} \end{pmatrix}$$

$$P = \frac{1}{\sum_0^n P_{i,n}} (P_{i,k} \quad P_{i,j} \quad P_{i,l})$$

where, P is the probability of selecting a node via which data can be sent to the sink l . The process flow after the estimation of the $\overline{RC}_{i,j}$ value is shown in the flow diagram below which will be similar to that of EARQ (Fig. 2).

The main advantage of the EARQ method is that the probabilistic method does not use redundant paths for data transmission and hence the network lifetime can be increased. After the introduction of the realistic energy cost parameter, the EEARQ outperforms EARQ in increasing the network performance and lifetime.

RESULT ANALYSIS

The simulation of the EARQ and EEARQ schemes are performed in the network simulator to analyze the network performance and energy efficiency. Network simulator is a discrete event simulator in which a scenario is created to perform simulations of the proposed enhancement over the comparison baseline. The simulation parameters used are listed in the Table 1.

To analyze the network performance, the packet delivery ratio, loss ratio and delay are measured.

Packet delivery rate: The Packet Delivery Rate (PDR) indicates how efficiently data is transmitted across the network. It is the ratio of the total packets received successfully per unit time. It can otherwise be called as the delivery success ratio and is estimated by the Eq. (6) that follows:

$$PDR = \frac{\sum \text{Packets Recv}}{\text{Time}} \quad (6)$$

The packet delivery of the EEARQ is greater than that of the EARQ protocol. This is because the reliability increases when the high energy nodes are selected for data transmission as the transmission power is directly proportional to the potential energy in the node (Fig. 3).

Packet loss rate: The total loss occurring in the network is determined by the Packet Loss Rate (PLR) (Fig. 4). It is the ratio of the total packets lost to the

Table 1: Simulation parameters of EARQ and EEARQ

Parameter	Value
Simulation time	100 msec
Number of nodes	31
Routing scheme	EARQ
Traffic model	CBR
Initial energy	100 mJ
Simulation area	1000×1000
Transmission range	250 m

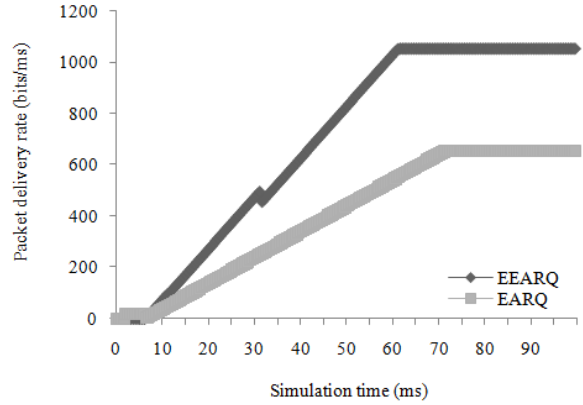


Fig. 3: Packet delivery of EARQ and EEARQ

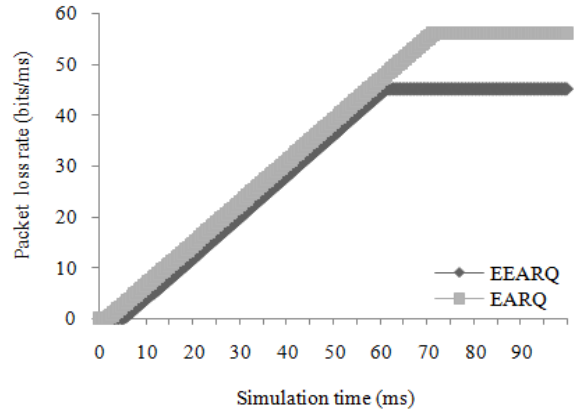


Fig. 4: Packet loss of EARQ and EEARQ

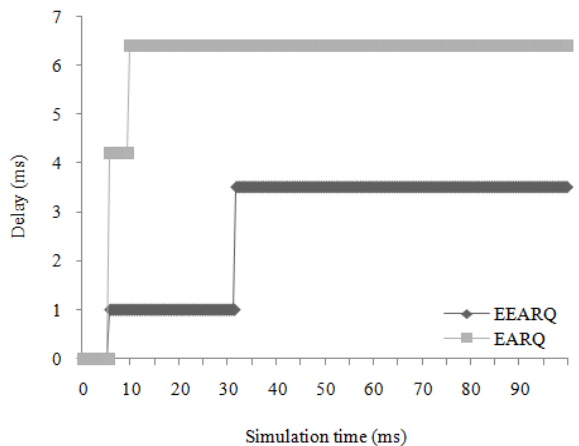


Fig. 5: Delay analysis of EARQ and EEARQ

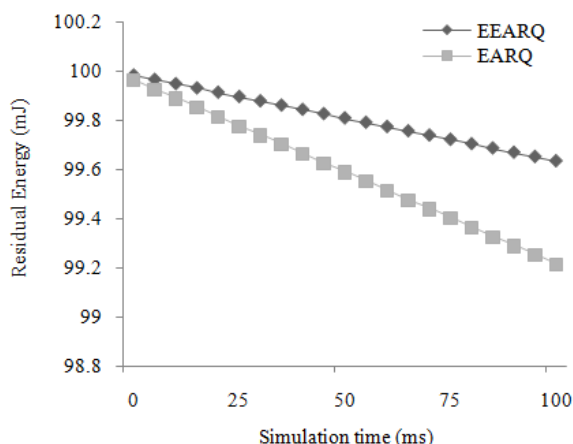


Fig. 6: Energy analysis of EARQ and EEARQ

total number of packets sent. Here it is calculated by the formula in Eq. (7):

$$PLR = \frac{\sum \text{Packets Loss}}{\text{Time}} \quad (7)$$

The packet loss occurred in the EEARQ is slightly reduced due to the reliability increase similar to that of the packet delivery.

Delay: The total delay occurring in the network during communication process is plotted against simulation time to monitor the delay in EARQ and EEARQ protocols. Delay is represented by Eq. (8):

$$\text{Delay} = \sum \text{Sent Time} - \text{Received Time} \quad (8)$$

The delay is reduced by approximately 3 msec due to the energy efficient routing in EEARQ when compared to the EARQ protocol (Fig. 5).

Energy: Energy analysis is performed by monitoring the rate at which residual energy varies over time. The energy plot is presented in the Fig. 6.

Figure 6 shows that the residual energy graph of EEARQ is higher than that of EARQ. This is because of the realistic energy cost parameter inclusion.

CONCLUSION

To enhance the lifetime of a wireless sensor network, we have presented in this study a realistic energy estimation enhancement on the EARQ protocol called EEARQ. A realistic energy cost measurement parameter is introduced into the EARQ that helps measure the energy per packet per unit time to integrate

the computational energy measurement and the actual energy expenditure. Through simulations it was proved that the EEARQ outperforms the EARQ in terms of quality of service like high packet delivery, low loss and low delay and also good energy efficiency.

Future works can be done to incorporate security schemes into the EARQ and EEARQ protocols to make it an ideal scheme. Integration of a matrix-based pairwise key establishment (Zhang *et al.*, 2013) during the matrix formation so that the security can be included in the network is a promising area to work in the future.

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