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RELIABILITY BASED MULTISTAGE ARQ FOR WIDE AREA WIRELESS SENSOR NETWORKS

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Abstract

Wide Area Wireless Sensor Network is a network of sensor nodes that are deployed in a larger area for applications like environment monitoring, wet land monitoring, precision agriculture, forest fire detection and surveillance applications etc. Collected data from the sensor nodes must be transmitted to the base station without any loss. To overcome the effect of loss, Automatic Repeat reQuest (ARQ) protocol is employed to retransmit the undelivered data packets. In multi-hop scenario, end-to-end ARQ protocol experience frequent retransmissions which leads significant energy consumption and in hop-by-hop ARQ protocol each node is expected to have high energy and larger buffer capacity for retransmitting and caching the data packets. Both these requirements are not always practical in wide area networks. In this paper, channel aware reliability based multistage ARQ (RARQ) is proposed to achieve reliable and energy efficient communication. According to the channel quality the multi-hop path between source and base station is fragmented into various ARQ segments. Each ARQ segment performs the packet re-transmission and confirmation individually. The performance of the proposed work is evaluated using NS-2 simulation tool. In the proposed RARQ scheme, data transmission reliability is achieved with limited energy consumption, lesser delay, and higher packet arrival ratio, compared to conventional ARQ schemes.

Keywords: ARQ, Energy, Networks, RARQ, Reliability, Retransmission, Sensor, Wireless, WSN.

1. Introduction

Wireless sensor network (WSN) is a network of large number of low power sensor nodes equipped with radio communication devices. These nodes are distributed in wider area for various applications like disaster monitoring, wet land monitoring, smart grid, environmental monitoring, and surveillance [1]. All these applications require reliable and long-term service. The data gathered by the sensor nodes from the monitoring field are communicated wirelessly to a base station or sink. Unreliability in data transmission causes false data report, longer transmission delay, data loss and sometimes service failure too. This urges the demand of energy efficient scheme to achieve high reliability. Either by importing packet redundancies or by performing retransmission schemes data reliability can be improved [2].

Forward Error Correction (FEC) retrieves the actual data in corrupted packet with predetermined redundancy. Based on environment severity, error patterns may change very often totally. Large amount of redundancy may alleviate the problem, but at the cost of more energy and bandwidth consumption. For this reason, FEC is quite suitable for infrastructure-based networks like wired local area network and cellular mobile network etc. ARQ schemes are given more attention in WSNs for providing data transmission reliability. But ARQ impose more energy consumption for retransmission of several packets. This in turn burdens the battery powered sensor nodes with limited energy supply in WAWSNs. Also, a convenient ARQ scheme must be identified in such a way that it should not introduce much complexity to the nodes as well as the network cost.

Traditional ARQ schemes can be categorized as end-to-end ARQ and hop-by-hop ARQ. In end-to-end ARQ scheme, originally transmitted packets must reach the destination after taking multiple hops, sometimes the packets might be lost on the way, or it may be corrupted before it reaches the sink. Receiver identifies the error in the packets or loss of packets and send negative acknowledgement back to the source node. Such acknowledgments and retransmitted data packets cause longer transmission delay and additional energy consumption. Delay will be added up when the retransmitted packets are lost again. Intermediate nodes in the route are totally unaware of packets lost, that may lead to reception failure and retransmission. The loss of packet or error in the packet may occur at any intermediate node in the route. If retransmission is initiated by the same node where it is identified, then retransmission path is reduced and in turn delay will be less.

In hop-by-hop ARQ scheme, every intermediate node between the source node and destination node check for the corrupted packets or loss of packets. The node which identifies the packet loss must send an acknowledgment to the source node and start the retransmission immediately. Each node in the path is involved in checking the packet status resulting in larger packet delay and energy consumption. To meet this requirement, every node in the network must be equipped with enough buffer and power supply, which will crucially affect the usage of WAWSNs.

To address the above mentioned limitations, this paper proposes RARQ for wide area WSNs. Reliability can be achieved with reasonable energy consumption and low packet delay in the proposed RARQ. The main features of RARQ are as follows:

i. Any relay node, in the route experiencing loss of packets, is capable of initiating the process of retransmission to the destination node. So, confirmation messages and retransmitted packets experience reduced transmission path.

ii. RARQ provide flexible, and energy efficient retransmission scheme based on the awareness on the channel quality. Required reliability can be achieved without fixing the session for ARQ.

iii. RARQ can be implemented easily with existing ARQ schemes in WSNs.

The rest of the paper is organized as follows: Section 2 describes the various ARQ schemes related work in WSN. In section 3, system model is presented. Proposed RARQ protocol and mathematical analysis is discussed in detail in section 4. In section 5, the performance of the proposed scheme is evaluated and compared with the performance of conventional ARQ schemes. Section VI presents the conclusions.

2. Related Works

In the literature, several algorithms were proposed to increase the efficiency of ARQ error control schemes. Hybrid Automatic Repeat Request (HARQ) is a combination of FEC and ARQ schemes meant to increase the transmission efficiency of ARQ schemes. Performance of HARQ is analyzed for time-variant multipath slow fading wireless channel [3]. Performance of HARQ and enhanced HARQ in WSN is studied [4, 5]. It is depicted that, even though FEC is combined with ARQ for error correction, these hybrid schemes are more appropriate for fixed networks. Vaze [6] derived the expressions for throughput, delay, and reliability tradeoff with ARQ in Ad hoc networks. Optimal number of hops between source and destination node is decided based on the transmission capacity and the type of ARQ mechanism adapted. The analysis is done for infrastructure less networks but how far it is applicable for infrastructure network is not known.

Vuran and Akyildiz [7] presented the cross-layer analysis of error control in wireless sensor networks. Performance of FEC, ARQ and HARQ were evaluated with hop length extension between the nodes and transmission power control by considering the effect of MAC. Here BCH and RS codes are used as FEC codes. They consider broadcast wireless channel model and multi-hop structure of WSN for analytical modelling. Results prove that FEC and HARQ are having improved performance in terms of latency, energy efficiency and end-to-end packet error rate. Once the nodes are deployed we cannot extend the hop length, which is not taken into consideration.

Cross layered ARQ concepts were introduced as an alternative to conventional schemes to enhance the efficiency of ARQ schemes. The extremely related information in different layers is combined for the intention of gaining the advantage of resources and adapting to the circumstances and constraints [8, 9]. Yang et al. [8] developed a cross-layer framework for adaptive modulation in physical layer to reduce the packet loss probability and truncated ARQ in data link layer to minimize the number of re-transmissions. The limitation is that the truncated ARQ presented in the work is implemented with respect to the cognitive radio resource requirements. Cross Layer ARQ (CL-ARQ) termed as new feedback ARQ makes use of HARQ acknowledgment methodology internally [9]. CL-ARQ removes the ARQ related packet overhead, improves the throughput and reduces the average delay when compared to conventional methods. But the suitability of this protocol for low power networks is not discussed in the paper.

Predojev et al. [10] studied the suitability of Cooperative - ARQ strategies in low power wireless networks and also optimized the energy efficiency of ARQ using cooperative transmission. Cooperative ARQ is implemented when there is a shadowing for a specific source. The shortfall is only two hop paths are considered for analysing the energy efficiency of proposed cooperative- ARQ. Cooperative ARQ [11] is more advantageous in terms of energy efficiency but in multi-hop scenario it is quite complex to achieve the coordination among the source, sink and intermediate nodes.

Jin et al. [12] proposed energy efficient data link layer adaptive error control method for wireless sensor networks. With the received signal strength value, the energy efficiency of FEC, ARQ and HARQ are determined for different values of communication distances between motes and link layer frame lengths [13-16]. Low error reporting rate sensors are considered for the analysis. Also least performing stop-and-wait ARQ protocol is employed for error control, which consumes less energy with more delay [12]. Lee et al. [17] proposed a Channel Adaptive Acknowledgment (CA- ACK) mechanism, where throughput is increased by adaptively transmitting the ACK based on wireless channel conditions. A threshold is set for the frame error rate of the channel, if the frame error rate is greater than the predefined threshold, then an ACK is transmitted, else no ACK is transmitted. The effect of original ARQ is improved in IEEE 802.15.3 by adapting CA-ACK for different reliability requirement and latency values, but it is not much energy efficient. Throughput is acceptable for varying channel conditions as well as the payload size, but the energy efficiency is not addressed in this work.

Zhang and Long [18] proposed an energy-aware hybrid ARQ scheme to ensure energy efficiency with the assurance of transmission reliability. The authors evaluated the energy consumption of each node assuming a flat circle network and analysed the various cases under which the proposed scheme is efficient than the traditional one. The authors also studied how to select parameters for the presented work to achieve better performance. Simulation results depicted the possibility of reduced energy consumption and thereby improvement in network lifetime. Jung and Choi [19] proposed an algorithm that combines hybrid ARQ operation with an autonomous retransmission technique to ensure a data packet is transmitted irrespective of whether or not the packet is successfully decoded at the receivers. The authors developed a methodology that adjusts the number of autonomous retransmissions for realistic practical scenarios and demonstrated that the work achieves higher spectral efficiency than existing hybrid ARQ techniques. The authors explored a practically applicable multicast transmission scheme in WSNs that can enhance spectral efficiency while ensuring acceptable Quality of Service.

Razali et al. [20] studied and analysed the different types of error correction schemes and existing hybrid ARQ mechanisms over different Bit Length and Node Densities. The authors inferred that as the network get congested; the error rate as well as the energy consumption increases thereby reducing the network lifetime. The results depicted that implementation of proper error correction codes considering the network conditions, can address the issue of energy consumption and transmission reliability. Barati et al. [21] proposed a reliable data transport protocol for wireless sensor networks. Usually ARQ and FEC are implemented for reliable data transport over WSN. Here the authors investigated a novel method in which an efficient moduli set in redundant residue number system has been employed. The modulus set is exploited as a means for adding redundancy to transmitted data. Error control is implemented in hop by hop manner. From the simulation results the authors inferred that the presented work achieves reduction in energy consumption with acceptable packet delivery ratio.

Kadel et al. [22] presented an overview of the different types of error correction schemes for wireless sensor networks. The authors conducted the review based on three criteria namely Forward Error Correction, adaptive error correction techniques, and other techniques. The review revealed that there are limited works on error correction schemes design on a realistic network model such as a multi-hop WSN model. The authors also presented possible research challenges and opportunities related to error correction schemes implementations for WSN.

In this paper, we paid attention to energy efficiency of the ARQ by considering reliability as a factor for data transmission and dividing the whole route into multiple paths. Reliability based multistage ARQ avoids the need for retransmission from the original source and in turn reduces the energy consumption and delay to a greater level.

3. System Model

The proposed framework and the system model are presented in this section.

3.1. Framework

As outlined above, reliability based ARQ attempt to provide energy efficient, reliable, reduced delay ARQ scheme. To reduce the complexity of the analysis, without loss of generality, the following assumptions are made with respect to WAWSN system:

- The WSN nodes are deployed in wide area at a fixed location, with one sink node. Several sensing WSN nodes can send data packets to the sink node. The nodes are almost uniformly distributed. Based on the requirement of application, sink node can be placed anywhere in the wide area.
- In wide area WSN tree structure routes are identified by using routing algorithm. Sink nodes will be the root and the wireless link which connects nodes forms the branches of the tree. Links that connect the WSN nodes are bi-directional links.
- Every deployed sensor node has sufficient buffer capacity to store the packets temporarily. Buffer size used by the cache packets is very less when compared to the capacity of the buffer.
- The data packets sent by the source nodes takes multiple hops and reach the sink nodes sequentially except the packets that are lost on the path.
- Generally, the sink node or base station is provided with external power supply with more processing capability. So, the energy consumption and resources requirement of the sink nodes is not considered.
- No positive acknowledgment ACK is sent by receiver to acknowledge the reception of data packets. Instead, negative acknowledgment (NAK) is used to indicate the loss of current packet and at the same time it also implicitly indicates

the reception of previous packets. The reason for using NAK is that the number of lost packets will be less than the amount of successfully received packets.

3.2. RARQ Mechanism

Consider N0, N1, N2 …Nn are the nodes selected randomly from the deployed WSN which are assumed to be in linear array model as shown in Fig. 1. Node N0 senses the data and transmits the packet to N1, intermediate nodes N2, N3…. Nn relay the data packets until it reaches the sink node or base station. For simplicity, it is assumed that the distance between all the wireless nodes is equal. The probability to receive a packet by the sink node should not be less than the required reliability Rreq in the wireless channel. Initially, all the nodes in the path are restricted from providing any packet validation and initiating retransmission.

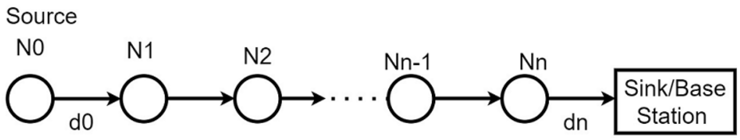

Fig. 1. Multihop llinear array sensor network model.

RARQ works in two steps, firstly based on the channel quality; reliability is calculated between source nodes to all the hop-by-hop intermediate nodes. Rreq is the required reliability for a successful transmission and reception of data packets in the multi-hop transmission route between sources and the sink node. More the hops in the route lead to more the probability of packet loss. Let 'p' be the probability of receiving any packet correctly by its one hop destination node sent by any node. The packet loss probability during the transmission is given by $q = 1 - p$. Secondly, if the reliability of any relay node is lesser than the Rreq, those relay nodes are marked as ARQ nodes. These ARQ nodes must temporarily store the data packets and perform packet confirmation or initiate retransmission to its adjacent ARQ nodes. Figure 2 depicts the working of RARQ in chosen route of wide area WSNs. The source node N0 and intermediate nodes N1, N2, N3…Nn forms the route from N0 to sink node. When any of the relay nodes experience any packet loss on the route in the channel, either source node or any of the ARQ nodes must retransmit the packet. The multi-hop route between the source and sink node is fragmented into different ARQ segments. For example, in Fig. 2, based on the required reliability, the path comprises of three ARQ segments. After identifying the packet loss, relay node will send a NAK to nearest ARQ node or source node based on the ARQ segment. In ARQ segment1, lost packet is retransmitted by source node, whereas in ARQ segment3, sink node will send NAK to the nearest ARQ node for retransmission of lost packets instead of the source node.

The algorithm of selecting ARQ node in the multistage RARQ scheme is presented in Fig. 3. In the source node N0, the reliability is set as 1. Reliability is calculated from source to each node in the path. ARQ technique is not applied while calculating the reliability and hence the lost data packets will not be retransmitted. Reliability (*Ri*) is calculated for node Ni, if *Ri* is greater than or equal to the required reliability *Rreq*, i.e., $Ri \geq Rreq$, then that sensor node is assigned as a normal relay node. In this case node Ni, will ignore the packet loss if there is any. Else if $Ri < Rreq$, then that node is identified as ARQ node. Based on the reliability value many ARQ nodes can be identified from source node to destination node. All the packets relayed by these ARQ nodes must be cached until it gets confirmation from the next node in terms of acknowledgment and do the retransmission if there is any loss of data.

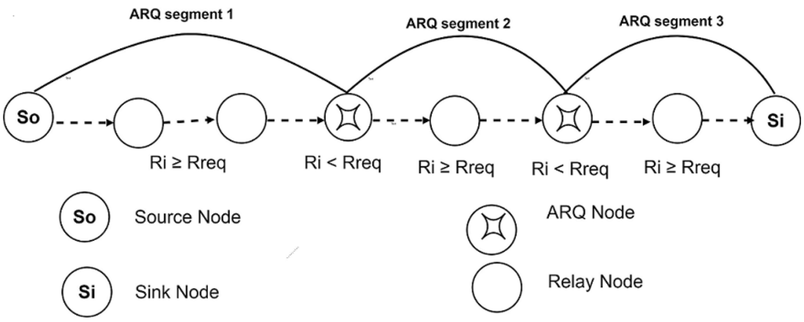

Fig. 2. RARQ in the chosen route of wide area WSNs.

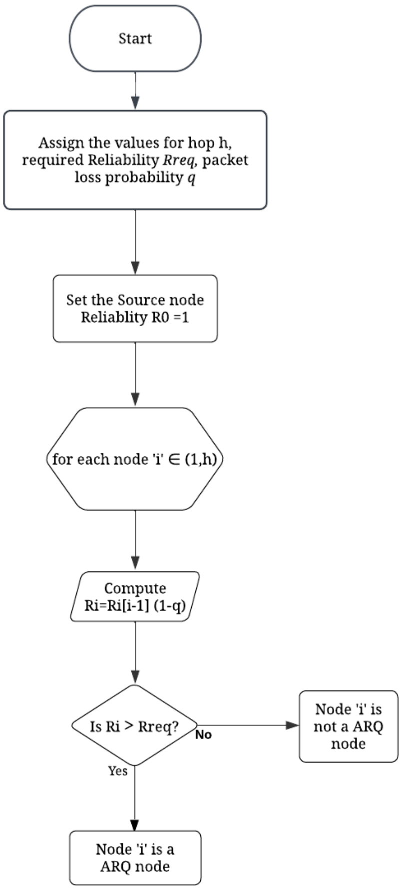

Fig. 3. ARQ node selection in multistage RARQ.

4. Mathematical Analysis

In this section, analytical models of performance metrics like average packet delay, total energy consumption and packet arrival ratio of the network, for the proposed RARQ scheme is presented. For ease of analysis, it is assumed that multi-hop path is available between the source node N0 and sink node. There are Nn +1 nodes in the path with Nn hops as shown in Fig. 1. In the multi-hop path, assume hop n connect the nodes Nn-1 and Nn, node Nn-1 after transmitting the block message of m packets to node Nn, enters receiving mode. Now node Nn will check for the correctness of the data and transmit ACK or NAK to Nn-1, depending on whether data is successfully received or not. We use conventional stop - and - wait ARQ scheme as fundamental ARQ scheme and use NAK for retransmission of lost packets.

Metrics

The following metrics were employed to evaluate the performance of the proposed localization scheme.

A. Packet delivery ratio

The Packet Delivery Ratio (PDR) metric depends on factors like size of the packet, number of nodes in the network, transmission range of the nodes and the network configuration. PDR is defined as number of data packets delivered successfully to the receiving node to the number of data packets transmitted by the source node which is given by

$$PDR = \frac{\sum_{s=1}^{e} J_s}{\sum_{y=1}^{e} G_y} \tag{1}$$

where e is total number of source/destination nodes in the widely deployed sensor network. *J* is the total number of packets received by destination nodes and G is the total number of packets sent by the source node in the wireless sensor network.

B. Average packet delay

Let us consider the packet length as *L* and *n* number of hops are in the path between source and destination. Assume any hop *i* of the n hop path from source node to destination. The amount of delay experienced by the packet over hop *i* is sum of transmission delay, propagation delay and transition delay. Average packet delay should be minimum to avoid transmission failure and timeout. In RARQ method, a data packet from source node will be relayed until an ARQ node finds the packet is lost. ARQ node will intimate about the packet loss to previous node with a NAK packet of length L_{na} and data packet length is greater than NAK packet. Also, the loss of NAK packets is neglected.

With *R* as the data transmission rate and n1 as number of hops in first ARQ segment, the packet delay for the first transmission in first ARQ segment is represented as

$$D_1 = \sum_{i=1}^{n1} \frac{L}{R} + T_i \tag{2}$$

where n1 is number of hops in first ARQ segment. The variable T_i is the sum of propagation delay, transition delay and processing delay which is given by

$$T_i = T_{prop} + 2T_{trans} + T_{proc} \tag{3}$$

where T_{trans} is the transition delay for single transmission, T_{prop} is the one round trip time for propagation and T_{proc} is delay for identifying errors with data at each node, till the successful delivery of data packet in one ARQ segment retransmission will take place. The same will be repeated for all the ARQ segments in the path between source and destination.

Let R_{RARQ} be the reliability metric for the proposed reliability based ARQ method and w_{RARQ} be the maximum transmission times, considering the first transmission and the retransmissions of data packet. Then we can write

$$R_{RARQ} = [1 - (1 - p^{n1})^{w_{RARQ}}]^{S_n} \tag{4}$$

where S_n is the number of ARQ segments in the path between source and destination. From Eq. (4) we can get the maximum number of transmissions of data packet as

$$w_{RARQ} = f^{-1}(R_{RARQ}) \tag{5}$$

Thus, there might be retransmission in each ARQ segment, in the path. The maximum transmission times will be different for each segment. After considering the maximum transmission times of data packet in the first ARQ segment, Eq. (2) can be rewritten as

$$D_1 = \sum_{i=1}^{n1} \left(\frac{L}{R} + T_i\right) w_{RARQ_1} \tag{6}$$

Therefore, the average delay of a data packet from source node is

$$D_{avg} = \frac{1}{S_n} \sum_{x=1}^{n} D_x w_{RARQx} \tag{7}$$

where,

$$D_x = \sum_{i=1}^{x} \left(\frac{L}{R} + T_i\right) w_{RARQx} \tag{8}$$

C. RARQ energy consumption analysis

A critical constraint on sensors networks is that sensor nodes employ batteries. A second constraint is that sensors will be deployed unattended and in large numbers, so that it will be difficult to change or recharge batteries in the sensors. Therefore, all systems, processes and communication protocols for sensors and sensor networks must minimize power consumption. Energy consumption refers to the usage of energy during transmission, buffering, retransmission, reception, packet drop and many other factors.

For the proposed RARQ method, the total energy consumed for transmitting m data packets over the network is evaluated with reference to the model given in Fig. 2. Consider i^{th} hop in the n hops route which connects source and destination node. The total energy consumed is the summation of energy consumed for data packet and negative acknowledgment transmission and reception. The total energy can be calculated as follows:

$$E_i = E_{tr,i} + E_{rx,i} + E_{tr,i}^{NAK} + E_{rx,i}^{NAK} \tag{9}$$

where $P_{tr,i}$ is the energy consumption of transmission of data packets and $E_{rx,i}$ is the energy consumption of the reception of data packets. $E_{tr,i}^{NAK}$ and $E_{rx,i}^{NAK}$ are the amount of energy consumed for transmitting and receiving negative acknowledgment packets, respectively. The energy spent on transmitting the data packets can be evaluated as

$$E_{tr,i} = mP_{tr,i}T_{tr}^{D} \quad (10)$$

where $P_{tr,i}$ is power needed to transmit through hop i and T_{tr}^{D} is the transmission delay of the data packet. Similarly, the energy consumed for receiving the data packets over the i^{th} hop is given by

$$E_{rx,i} = mP_{rx,i}T_{rx}^{D} \quad (11)$$

$E_{tr,i}^{NAK}$, the measure of energy spent for transmitting NAK can be expressed as

$$E_{tr,i}^{NAK} = P_{tr,i}T_{tr,i}^{NAK} \quad (12)$$

where $T_{tr,i}^{NAK}$ is the transmission time required for sending the negative acknowledgment. Also, it is assumed that the NAK packets are always delivered to the intended node with high reliability. The energy consumed for receiving NAK is one fifth of the energy consumed for transmitting the negative acknowledgment. Thus, for the n hops path, the total energy consumption is given as

$$E_t = \sum_{l=1}^{n-1} E_i \quad (13)$$

5. Results and Discussions

The performance of the proposed Reliability based multistage ARQ is evaluated using NS-2 simulation tool. Performance results of RARQ method is compared with conventional ARQ protocol in terms of Packet delivery ratio, average packet delay, and total energy consumed in the network. The proposed RARQ method is implemented in NS-2 simulator. Figure 4 depicts the sample network deployed for simulation study. The simulation parameters used for simulation and analysis are given in Table 1. For RARQ simulation 50 nodes are randomly deployed in 500m x 500m area. The maximum number of hops between source and destination is set as 10. The number of ARQ segments between the source and destination is based on the channel reliability and average number of hops between source and destination. For ease of analysis only one node is considered as the source node in the network which transmits 200 data packets. The size of the data packet and NAK packet are set as 60 bytes and 6 bytes, respectively. The sensor nodes initial energy is set to 90 J [12].

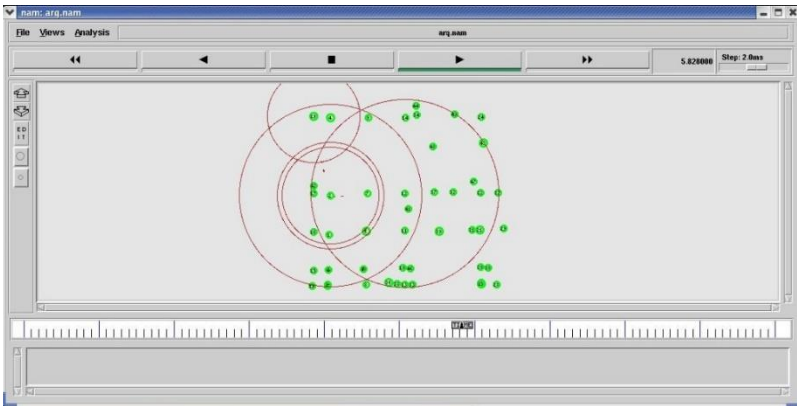

Fig. 4. NS-2 Network layout (50 nodes).

Table 1. Simulation Parameter settings.

Parameters	Values
Number of nodes	50
Dimension X	500 m
Dimension Y	500 m
Channel type	Wireless Channel
Radio propagation model	Two-ray ground model
Antenna type	Omni Antenna
Network interface type	Phy/WirelessPhy
Interface queue type	Queue/Drop Tail/PriQueue
MAC type and protocol	802.11 and ARQ/RARQ
Predefined Reliability	80%
Packet size	2000 bits uniformly
Packet interval	0.05s
Traffic type	Constant Bit Rate (CBR)
Lost packet notification	Negative Acknowledgment (NAK)
NAK packet size	64 bits uniformly
Transmission power	0.6 W
Reception power	0.3 W
Initial energy	90 J

The proposed RARQ method is compared with conventional end to end ARQ method for Packet Delivery Ratio (PDR) as function of time in Fig. 5. The plot of packet delivery ratio at the destination node is given for the network with the scale of 25 nodes. Figure 6 depicts the PDR for network scale of 50 nodes in the deployment area. From Figs. 5 and 6 it is inferred that packet delivery ratio of suggested RARQ method is high when compared to the conventional ARQ method. Irrespective of the number of nodes in the network, RARQ performs well in terms of PDR.

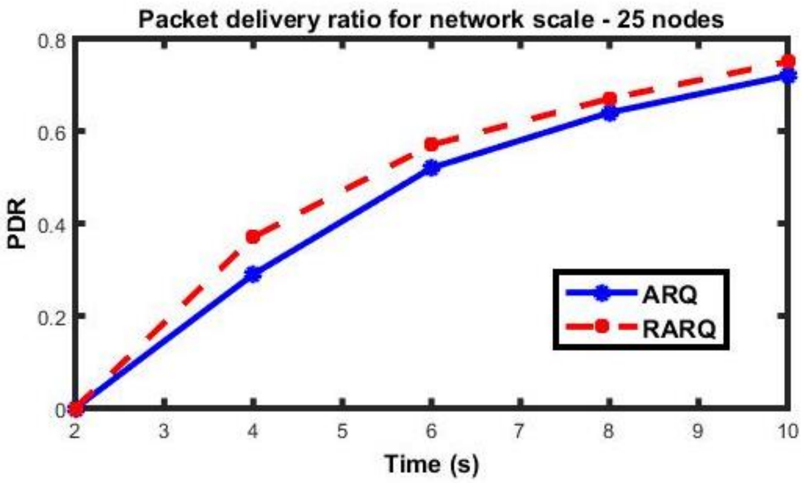

Fig. 5. Packet Delivery Ratio for network scale of 25 nodes.

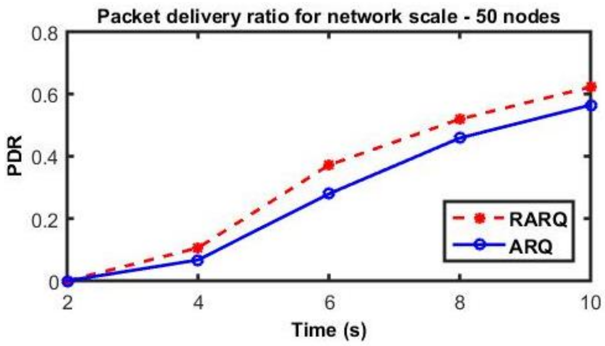

Fig. 6. Packet delivery ratio for network scale of 50 nodes.

Figure 7 compares the proposed method with traditional ARQ method for average packet delay against simulation time in seconds for network with 25 nodes. The average packet delay for 50 nodes network is presented in Fig. 8. It is inferred that irrespective of the size of the network, the RARQ scheme has lower average packet delay compared to that of end-to-end ARQ. When the network scale increases, the average packet delay of all ARQ schemes increase obviously, but the increase in delay with the RARQ scheme is much less.

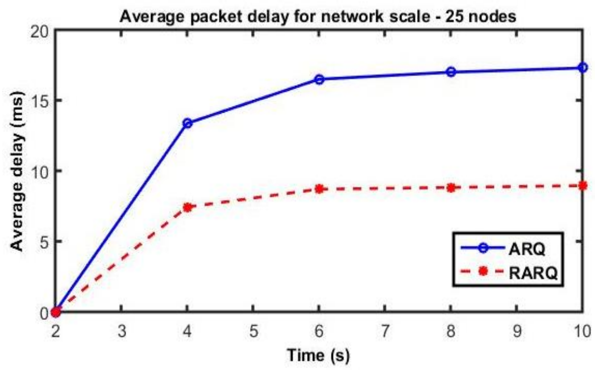

Fig. 7. Average packet delay for 25 nodes network.

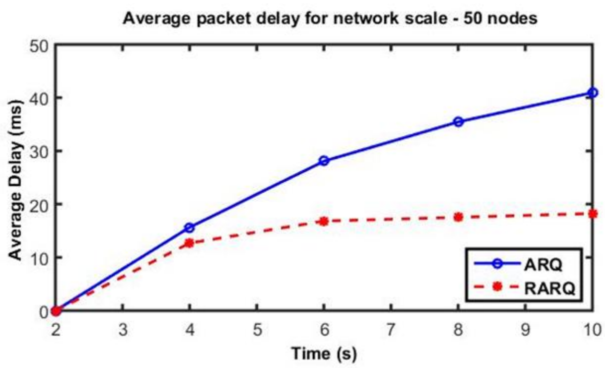

Fig. 8. Average packet delay for 50 nodes network.

Figures 9 and 10 depicts the total energy consumption under different network conditions. It is observed from both the graphs, that multistage RARQ protocol consumes lesser energy than the traditional ARQ scheme. From Fig. 9 for network with 25 nodes, the RARQ method has much lesser impact on energy consumption with respect to the simulation time. When the network size increases, the RARQ method plays a vital role on reducing the length of retransmission route. As only NAK packets are carried in the retransmission route, the energy consumed is close to the conventional ARQ method. So, RARQ method is economical to realize and implement in wide area WSN.

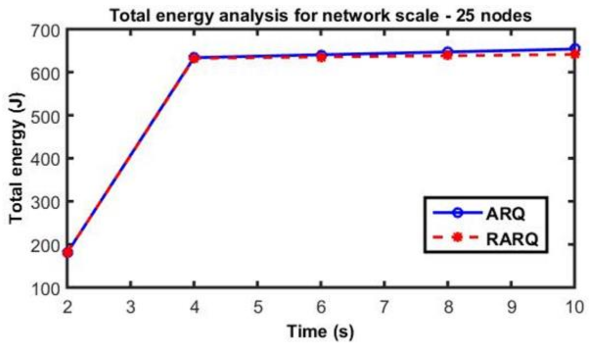

Fig. 9. Total energy analysis - 25 nodes network.

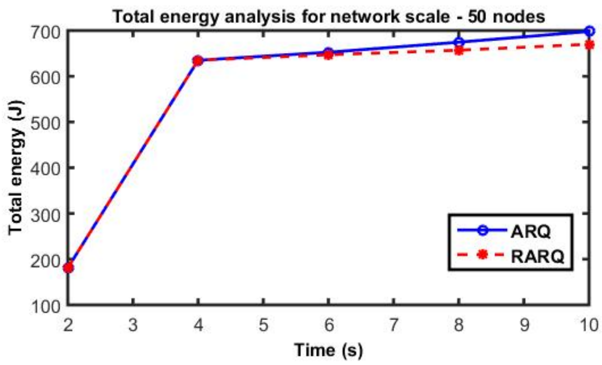

Fig. 10. Total energy analysis - 50 nodes network.

Figure 11 presents the variation of average packet delay against number of nodes. As the number of nodes increases in the network, average delay of the multistage RARQ method as well as end to end ARQ method increases. From the results, it is inferred that the average delay experienced in RARQ method is very low compared to that of conventional ARQ method. Average delay incurred by the packet transmitted using RARQ scheme is 78% less when compared to the traditional one. The reason being, the RARQ method initiates the retransmission of lost or damaged packet from the nearest ARQ node and not from the source node.

Figure 12 depicts the total energy consumption against number of nodes for RARQ method and ARQ method for the multi-hop route. RARQ outperforms the conventional end to end ARQ scheme. It is clearly depicted that for different conditions, the energy consumed by the RARQ method is much lesser. For increasing number of nodes, RARQ is more advantageous. For 50 nodes network scenario, the energy is 58% saved in RARQ. RARQ is more energy efficient compared to the conventional ARQ scheme.

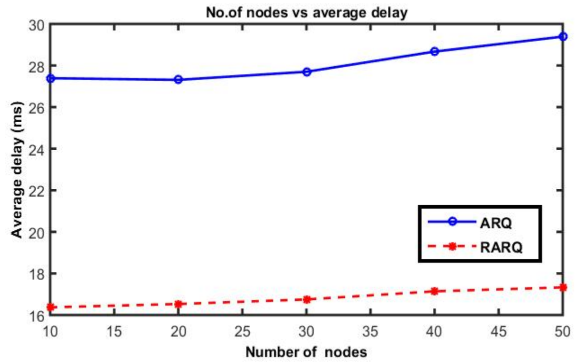

Fig. 11. Average packet delay vs. number of nodes.

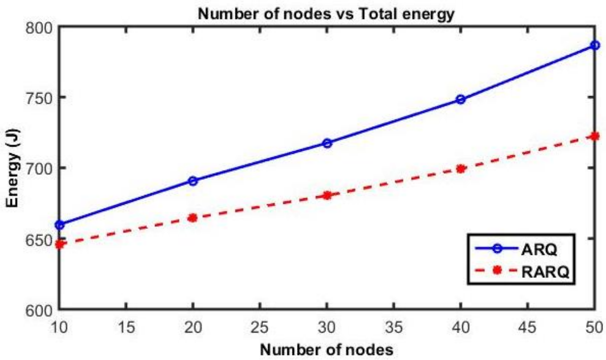

Fig. 12. Total energy consumed vs. number of nodes.

6. Conclusions

Reliability based multistage ARQ for Wide Area Wireless Sensor Networks was proposed and presented. Reliability based multistage ARQ proposed in this paper divides whole multi-hop wireless route into multiple segments and performs end to end ARQ for each ARQ segment. Each ARQ nodes does the packet confirmation and required retransmission depending on the reliability of the local channel conditions. Performance of the presented work was evaluated using NS-2 simulation tool. Performance analysis of the RARQ schemes shows a good balance with that of conventional end to end ARQ in terms of packet delivery ratio, energy consumption and average packet delay. Totally the network cost is much lesser in RARQ. The RARQ scheme is currently studied for stationary WSNs, providing optimal method in network design and deployment. In future, this work can be further extended in enabling the RARQ scheme to support dynamic networks. In addition, the influence of jitter, throughput, and overhead can be studied.

References

1. Akyildiz, I.F.; Su, W.; Sankarasubramaniam, Y.; and Cayirci, E. (2002). Wireless sensor networks: a survey. *Computer Networks*, 38(4), 393-422.
2. Lu, R.; Li, X.; Liang, X.; and Shen, X. (2011). Grs: The green, reliability, and security of emerging machine to machine communication. *IEEE Communications Magazine*, 49(4), 28-35.
3. Shen, C.; and Fitz, M.P. (2011). Hybrid ARQ in multiple-antenna slow fading channels: performance limits and optimal linear dispersion code design. *IEEE Transactions on Information Theory*, 57(9), 5863-5883.
4. Eriksson, O.; Bjornemo, E.; Ahlen, A.; and Gidlund, M. (2011). On hybrid ARQ adaptive forward error correction in wireless sensor networks. *Proceedings of the IECON* 2011 - 37*th* *Annual Conference of the IEEE Industrial Electronics Society*, Melbourne, VIC, Australia, 3004-3010.
5. Dohl, J.; and Fettweis, G. (2011). Energy aware evaluation of LTE hybrid-ARQ and modulation/coding schemes. *Proceedings of the* 2011 *IEEE International Conference on Communications* (*ICC*), Kyoto, Japan, 1-5.
6. Vaze, R. (2011). Throughput-delay-reliability tradeoff with ARQ in wireless ad hoc networks. *IEEE Transactions on Wireless Communications*, 10(7), 2142-2149.
7. Vuran, M.C.; and Akyildiz, I.F. (2006). Cross-layer analysis of error control in wireless sensor networks. *Proceedings of* 2006 3*rd Annual IEEE Communications Society on Sensor and Ad Hoc Communications and Networks*, Reston, VA, USA, 25-28.
8. Yang, Y.; Ma, H.; and Aissa, S. (2012). Cross-layer combining of adaptive modulation and truncated ARQ under cognitive radio resource requirements. *IEEE Transactions on Vehicular Technology*, 61(9), 4020- 4030.
9. Kim, D.; Choi, Y.; Jin, S.; Han, K.; and Choi, S. (2008). A MAC/PHY cross-layer design for efficient ARQ protocols. *IEEE Communication Letters*, 12(12), 909-911.
10. Predojev, T.; Alonso-Zarate, J.; and Dohler, M. (2012). Energy efficiency of cooperative ARQ strategies in low power networks. *Proceedings of the* 2012 *Proceedings IEEE INFOCOM Workshops*, Orlando, FL, USA, 139-144.
11. Yu, G.; Zhang, Z.; and Qiu, P. (2007). Efficient ARQ protocols for exploiting cooperative relaying in wireless sensor networks. *Computer Communications*, 30(14-15), 2765-2773.
12. Jin, Y.; Chang, J.; and Le, D. (2010). A high energy efficiency link layer adaptive error control mechanism for wireless sensor networks. *Proceedings of the* 2010 *International Conference on Computational Intelligence and Software Engineering*, Wuhan, China, 1-4.
13. Rappaport, T.S. (2001). *Wireless communications: Principles and Practice*. (2nd ed.). Prentice Hall.
14. Singh, M.P.; and Kumar, P. (2012). An efficient forward error correction scheme for wireless sensor network. *Procedia Technology*, 4, 737-742.
15. Kaythry, P.; Kishore, R.; and Priyanka, V.N. (2022). Performance analysis of LT code based HARQ error control in underwater acoustic sensor networks. *Journal of Marine Engineering and Technology*, 21(1), 54-64.

16. Tian, Z.; Yuan, D.; and Liang, Q. (2008). Energy efficiency analysis of error control schemes in wireless sensor networks. *Proceedings of the* 2008 *International Wireless Communications and Mobile Computing Conference*, Crete, Greece, 401-405.
17. Lee, J.-I; Pack, S.; Kim, K.-H; and Kang, C.-H. (2009). Channel adaptive ACK mechanism in IEEE 802.15.3 wireless personal area networks. *Proceedings of the* 2009 *International Conference on Information Networking*, Chiang Mai, Thailand, 1-5.
18. Zhang, J.; and Long, J. (2017). An energy-aware hybrid ARQ scheme with multi-ACKs for data sensing wireless sensor networks. *Sensors*, 17(6), 1366.
19. Jung, Y.-H.; Choi, J. (2017). Hybrid ARQ scheme with autonomous retransmission for multicasting in wireless sensor networks. *Sensors*, 17(3), 463.
20. Razali, S.M.; Mamat, K; and Bashah, N.S.K. (2016). Implementation of hybrid ARQ (HARQ) error control algorithm for lifetime maximization and low overhead CDMA wireless sensor network (WSN). *Proceedings of the* 016 *IEEE Conference on Wireless Sensors* (*ICWiSE*), Langkawi, Malaysia, 71-76.
21. Barati, A.; Movaghar, A.; Sabaei, M. (2016). RDTP: Reliable data transport protocol in wireless sensor networks. *Telecommunication Systems*, 62, 611-623.
22. Kadel, R.; Paudel, K.; Guruge, D.B.; Halder, S.J. (2020). Opportunities and challenges for error control schemes for wireless sensor networks: A review. *Electronics*, 9(3), 504.