# Chapter 3
# Efficient Retransmission QoS-Aware MAC Scheme in Wireless Sensor Networks

**M. Kumaraswamy, K. Shaila, V. Tejaswi, K.R. Venugopal, S.S. Iyengar, and L.M. Patnaik**

**Abstract** In this paper, an Efficient Retransmission Random Access Protocol (ERRAP) is designed that combines scheme of collision avoidance and energy management for low-cost, short-range wireless radios and low-energy sensor nodes applications. This protocol focuses on efficient Media Access Control (MAC) schemes to provide autonomous Quality of Service (QoS) to the sensor nodes in one-hop QoS retransmission group in WSNs where the source nodes do not have receiver circuits. These sensor nodes can only transmit data to a destination node, but cannot receive acknowledgement or control signals from the destination node. The proposed scheme ERRAP provides QoS to the nodes which work independently on predefined time by allowing them to transmit each packet an optimal number of times within a given period. Our simulation results demonstrate the superiority of ERRAP scheme which increases the delivery probability and reduces the energy consumption.

## 3.1 Introduction

Wireless Sensor Networks (WSNs) consist of a large number of distributed nodes, that combine automated sensing, embedded computing and wireless components into tiny embedded devices. WSNs gather information or detect special events and communicate in a wireless fashion. WSNs provide a wide range of potential

M. Kumaraswamy (✉) • K. Shaila • V. Tejaswi • K.R. Venugopal
Department of Computer Science and Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bangalore, India
e-mail: kumarasm67@yahoo.co.in

S.S. Iyengar
Florida International University, Miami, FL, USA

L.M. Patnaik
Indian Institute of Science, Bangalore, 560 001, India

N. Meghanathan et al. (eds.), *Networks and Communications (NetCom2013)*, Lecture Notes in Electrical Engineering 284, DOI 10.1007/978-3-319-03692-2_3,

applications like healthcare, environmental monitoring, battlefield monitoring, remote sensing, industrial process control, surveillance and security etc. A typical Wireless Sensor Network consists of one or few sink nodes and a large number of data sensor nodes deployed, each source node generates data and transmits to the sink through common communication channel. In general, such networks consists of both transmitting and receiving circuits. However, in most applications the devices generally collect data and transmit to the sink node. The communication from sink node to source node is minimum. The receiver circuitry adds extra cost and also consumes significant amount of energy during process. Thus by using sensor data nodes with only transmitters, the device cost and the entire network infrastructure cost can be reduced. These wireless sensor devices are equipped with sensing, computation and wireless communication capabilities. Sensing tasks for sensors devices could be temperature, light, sound, humidity, vibration, etc. Random access scheme WSNs communication devices are low rate communication protocol are designed for low cost, low data rate and low power WSNs devices.

Optimal retransmission is the process of sending packets to the sink multiple number of times to achieve the maximum delivery probability. The efficient retransmission in WSNs is mainly focused on QoS in terms of packet delivery probability and energy efficiency.

In this paper, we consider WSNs that deals with QoS aware medium access control scheme of one-hop QoS group that has low complexity, less power consumption and optimum cost. Proposed scheme consists of network topology with more number of source nodes which are distributed and decentralized in one-hop communication range. In the present day environment every source node in a WSN is equipped with only transmitter module. The receiver module is avoided, since they consume more energy and are expensive due to the hardware complexity. The throughput requirement are low because the source collects and transmits the data to the sink. The sink node in the network has both transmitter and receiver and it receives the data transmitted by the source nodes. There are a large number of applications which use the above concept such as Smart Home Monitoring, Smart Environment, Intelligent Transportation and Medical Monitoring.

Most of the medium access control protocol are like polling, CSMA, Automatic Repeat Request (ARQ), collision avoidance/detection [1] and scheduled transmissions [2] are not effective because they need the ACK to transmit the next packet.

**Motivation** In many application scenarios of sensor networks, sensor data must be delivered to the sink node within time constraints. It is crucial to evaluate the performance limits, such as maximum data delivery and energy consumption of traffic loads under all conditions.

Hence, efficient retransmission, maximization of the packet delivery probability and energy efficiency have to be considered in designing WSNs.

**Contribution** This paper presents, Efficient Retransmission Random Access Protocol (*ERRAP*) provides QoS to the nodes using random access mode where each node transmits data packet by selecting variable slot randomly for adaptive data packet considering local environment. Nodes can only join the network during random access periods. The time interval between random access periods could be small. So, in the proposed protocol, nodes randomly decide whether it should retransmit to improve packet delivery depending on some pre-calculated efficient retransmission probabilities. The sink node receives exactly one error-free retransmission data packet without collision.

An analytical method to evaluate the maximum data delivery probability and minimum energy consumption is proposed. We design an Efficient Retransmission Random Access Protocol (*ERRAP*), is simple, lightweight, compatible with the 802.11b standard and provides maximum data delivery.

**Organization** The rest of the paper is structured as follows. Related works are discussed briefly in Sect. 3.2. An overview of the Background is given in Sect. 3.3. In Sect. 3.4 describes the Problem Definition, objectives and assumptions. Section 3.5 presents the System Model. Mathematical Model is developed for the One-Hop Retransmission in Sect. 3.6. Algorithm and Performance Evaluation are presents in Sects. 3.7 and 3.8. Conclusions are contained in Sect. 3.9.

## 3.2 Related Work

Pai et al. [3] designed a novel adaptive retransmission algorithm to improve the misclassification probability of distributed detection with error-correcting codes in fault-tolerant classification system for Wireless Sensor Networks. The local decision of each sensor is based on its detection result. The detection result must be transmitted to a fusion center to make a final decision.

Lu et al. [4] proposed a MAC layer cooperative retransmission mechanism and a node can retransmit lost packets on behalf of its neighboring node. However, although each lost packet can be recovered by a neighboring node, it still requires a new transmission for each retransmission attempt, which largely limits its ability to increase the throughput of the network.

Xiong et al. [5] consider cooperative forwarding in WSNs from a MAC-layer perspective, which means a receiver can only decode one transmission at a time. Qureshi et al. [6] propose a latency and bandwidth efficient coding algorithm based on the principles of network coding for retransmitting lost packets in a single-hop wireless multicast network and demonstrate its effectiveness over previously proposed network coding based retransmission algorithms.

Ruiz et al. [7] propose an architecture collaboration in which the MAC and routing protocols discover and reserve routes to organize nodes into clusters and to schedule the access to the transmission medium in a coordinated time-shared fashion. It achieves QoS and reduces energy consumption by avoiding collisions and considerably lowering idle listening.

Tannious et al. [8] have proposed an algorithm where a secondary node user exploits the retransmissions of primary node user packets in order to achieve a higher transmission rate. The secondary node receiver can potentially decode the primary node users packet in the first transmission.

Bai et al. [9] propose a design of IEEE 802.11 based wireless network for MAC that dynamically adjusts the retransmission limit to track the optimal trade-off between transmission delay and packet losses to optimize the overall network control system performance.

He and Li [10] propose the single-relay Cooperative Automatic Repeat Request (CARQ) protocol, in which the relay node is selected in a distributed manner; the relays use different backoff time before packet retransmission. In a dense network, due to high possible collision probability among different contending relays, an optimized relay selection scheme is introduced to maximize system energy efficiency by reducing collision probability.

Volkhausen et al. [11] focuses on cooperative relaying, that exploits temporal and spatial diversity by additionally transmitting status a relay node; such relaying improves packet error rates and transmit only once rather than on each individual hop along the routing path. This cooperation reduces the total number of transmissions and improves overall performance.

Wang et al. [12] propose the local cooperative relay for opportunistic data forwarding in mobile ad-hoc networks. The local cooperative relay select the best local relay node without additional overhead; such real time selection can effectively bridge the broken links in mobile networks and maintain connectivity.

## 3.3 Background

Sudhaakar et al. [13] propose a Medium Access Control scheme, which typically consists of large number of source nodes and are within one-hop communication range to one or few sink nodes. Each of these source nodes is equipped with only transmitter module in order to eliminate the cost due to hardware complexity and energy consumption of the receiver module. As a result, they are not capable of receiving any signals like ACK/NAK. The source nodes collect data and transmit a relatively small data frame to the sink nodes once a while and hence the throughput requirement of the source nodes is low. The sink nodes are the only nodes in the network that are equipped with receiver modules and are capable of receiving the transmissions of the source nodes.

## 3.4 Problem Definition

Consider a Wireless Sensor Network consisting of $M$ nodes as shown in Fig. 3.1, having source nodes and one or two sink nodes. All the WSNs nodes are within one hop transmission range of the sink. The source nodes do not have receiver unit, so it is impossible for sensor nodes to sense the channel either for collision detection or receive any acknowledgements from the sink node. The main objective of the proposed work is to

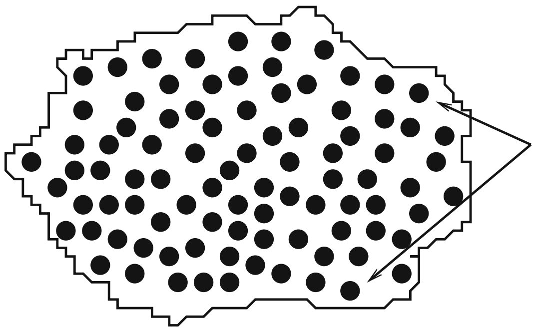


**Fig. 3.1** Nodes deployment in wireless sensor network

1. Maximize packet delivery probability.
2. Reduce packet retransmission.
3. Reduce energy consumption.

### *3.4.1 Assumptions*

(i) All nodes are homogeneous.
(ii) The nodes are randomly distributed within a area.
(iii) Packet generation rate at each node follows a Poisson distribution.

## 3.5 System Model

The *ERRAP* provides QoS to the nodes using random access mode where each node independently depending on local conditions transmits data packet by selecting variable slot randomly for variable data packet according to the number of sensors nodes. Nodes can only join the network during random access periods. The time interval between random access periods could be small. In the proposed protocol *ERRAP*, nodes randomly decide whether it should retransmit to help the packet delivery depending on some pre-defined efficient retransmission probabilities. The sink node receive exactly one error-free transmission packet in a slot, without collision. Our goal is to develop decentralized MAC protocol to provide QoS guarantees for both time-critical and non time-critical sensor applications. This is a challenge that has not been addressed by any existing approach. The most important metrics to analyze the QoS performance of MAC protocol is packet delivery probability and energy efficiency.

In WSNs, each sensor node data packets transmission duration is relatively small when compared to the data packets that are generated at a constant rate i.e., one packet every $T$ units of time. In addition, if a packet cannot be successfully delivered within a data generation $T$ units of time, the data packets is simply neglected. This makes sures that the new data packets have greater chance of being successfully delivered. Thus the maximum delivery probability that can be achieved by each individual sensor node increases eventually, so that all the nodes in the network achieve their required QoS in terms of data delivery probability.

## 3.6 Mathematical Model

### *3.6.1 One-Hop Retransmission*

We have assumed that the source nodes generate data at constant rate of one packet every $T$ units of time and the retransmission time for each packet is much smaller than the duration of packet transmission $T_p$. To achieve equal packet delivery probability by all the nodes in the WSNs. Under this assumption the packet arrival rate can be modeled as a Poisson distribution. The number of nodes in the network is denoted by $M$ and the number of retransmissions by each node for each packet is denoted by $y_k$. The notations are defined in Table 3.1.

The packet arrival rate of the source nodes can be modeled as a Poisson distribution and the probability that $p$ packets are transmitted in an interval $T_t$ with $Q(M)$ the probability of $M$ arrivals in one time slot is given by

$$Q(M) = \frac{(\beta T_t)^p}{p!} e^{-\beta T_t} \tag{3.1}$$

Where, $\beta$ is the rate of traffic generated by all other nodes inside the transmission range of a node and is equal to $\frac{(M-1)}{T} y$.

The probability that the packet transmitted by node $k$ does not collide, so it is same as the probability that no packet were transmitted by the other $M - 1$ nodes in an interval $2T_p$. Therefore $Q_{nc}$ is

$$Q_{nc} = e^{-2\beta T_p} \tag{3.2}$$

**Table 3.1** Notations

| Symbols | Meaning |
|---|---|
| M | Total number of sensor nodes |
| T | Data packet generation time |
| $T_p$ | Duration of packet transmission |
| $y_k$ | Number of retransmission |
| $\beta$ | Packet arrival rate |
| p | Number of packets |
| Q | Packet delivery probability |
| $T_t$ | Time of $p$ packet transmission |

The above discussion presents the probability that a packet transmitted by node $k$ is successfully received by the sink. However, node $k$ transmits $y_k$ copies of the packet at random instants in every time interval $T_p$. Hence the actual parameter of interest will be the probability that at least one of these $y$ copies is successfully received at the sink, which is defined as the QoS delivery probability of the node. The $Q(y_c)$, the collision transmission of delivery probability of each packet is given by

$$Q(y_c) = (1 - Q_{nc})^y \tag{3.3}$$

The probability of successful transmission of sensor data packet $Q(y_s)$ is given by

$$Q(y_s) = (1 - Q(y_c)) \tag{3.4}$$

Combining the above equations, we obtain

$$Q(y_s) = (1 - Q(y_c))$$

$$Q(y_s) = 1 - (1 - Q_{nc})^y$$

$$Q(y) = Q(y_s) = 1 - (1 - e^{-2\beta T_p})^y \tag{3.5}$$

The $Q(y)$ expresses the QoS delivery probability as function of the number of retransmissions attempted by each node in the interval $T_p$.

The maximum delivery probability $Q_{max}$ that can be achieved is given by

$$Q_{max} = 1 - (1 - e^{-2\beta T_p})^y \tag{3.6}$$

The above result gives relationship between the maximum delivery probability that can be achieved, the number of retransmission attempts that each node makes in every interval $T_p$ and the number of nodes $M$.

## 3.7 Algorithm

In this paper, the performance of retransmission algorithm *ERRAP* is discussed to find the solution to the optimization problem in one-hop QoS group containing $M$ nodes. The objective of the *ERRAP* algorithm is to find the optimal retransmission value between $y_{low}$ and $y_{high}$ that minimizes the total sensor network traffic and each node in WSNs achieves maximum delivery probability in background traffic.

*ERRAP* algorithm solves the problem of energy consumption and delivery probability.

The sensor nodes are randomly deployed and sends data packet to a sink node, $y$ number of times. All the WSNs nodes are within one hop transmission range of the sink and source nodes in the network to achieve the same delivery probability as shown in Algorithm 1. When a data packet is received by a node after transmitting $y$ number of times, in a given period. The arrival rate of packet is modeled as a poisson distribution and the maximum delivery probability is achieved in one hop retransmission.

**Algorithm 1:** EERAP algorithm

*Begin*

1. All $M$ Sensor Nodes are within the Sensing and Communication Range
2. Nodes are Randomly Distributed
3. All Source Nodes Send Data Packet to a Sink Node
4. Sink has information about each Source Node Location and ID
5. Each Node Energy Depends on Distance and Data Size
6. Each Source Nodes are Transmits $y$ copies at Random Instant
7. Data Packets are received within the given time Period at Sink
8. Delay from each Source Node to a Sink is same
9. Probability of Error is Minimized
10. Minimum Number of Retransmission $y$ times from one-hop QoS Group
11. Maximum Delivery Probability $Q_{max} \leftarrow 1 - (1 - e^{-2\beta T_p})^y$

*End*

## 3.8 Performance Evaluation

### *3.8.1 Simulation Setup*

The performance of *ERRAP* has been evaluated using ns2 simulator package to obtain packet delivery probability and energy consumption. A random flat-grid scenario is chosen for deployment of the nodes within $50 \times 50$ and $230 \times 230$ m area. In our simulation model, we use two-ray ground reflection model for radio propagation and omnidirectional antenna. The transmission bandwidth is set to 50 Mbps, each source node has only transmit circuit and no receiver and the number of nodes $M$ is 100, data arrival rate $T = 1$ ms and packet transmission time $T_p = 6.4 \times 10^{-4}$ ms.

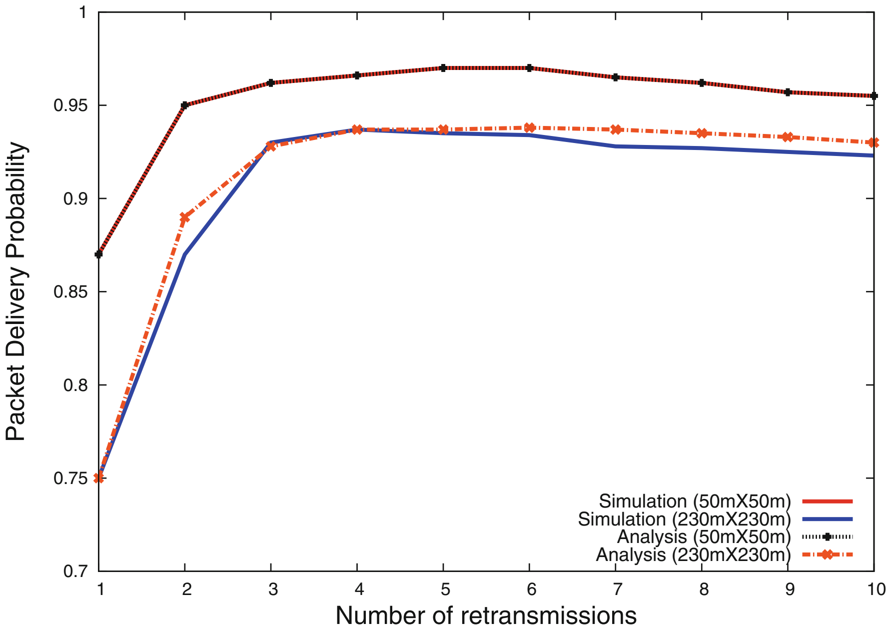


**Fig. 3.2** Packet delivery probability of one-hop retransmission simulation and analysis result

### *3.8.2 One-Hop QoS Group*

The results for *Q(y)* given in Eq. 3.4 for one-hop retransmission, consisting of $M = 100$ nodes is plotted in Fig. 3.2. It shows that the probability of the delivery of packets initially increases with the number of retransmissions, reaches maximum and then decreases. The simulation and numerical analysis results shows that the maximum delivery probability of *Q(y)* is 0.9990 for $50 \times 50$ m area when $y = 4$ or $y = 5$. The minimum delivery probability *Q(y)* is 0.978 is achieved for $3 \leq y \leq 9$. The *ERRAP* scheme minimizes the network traffic when $y = 3$ and maximizes the probability of delivery of data packets when the retransmission value $y = 4$.

The second set of curves of *ERRAP* of simulation results is comparable with the theoretical analysis. The delivery probability *Q(y)* is 0.96 when the nodes are randomly distributed in $230 \times 230$ m region. Since, the simulation performance of sensor nodes are poor in a large region, we assume that the packet loss is only due to channel errors and not due to collisions or interference.

The graph in Fig. 3.2 illustrates that the number of retransmission by each sensor node is reduced by choosing the value for $y$ as 3 or 4. This increases the probability of delivery, which in turn increases the lifetime of the sensor nodes. The simulation results are agree with the analytical results.

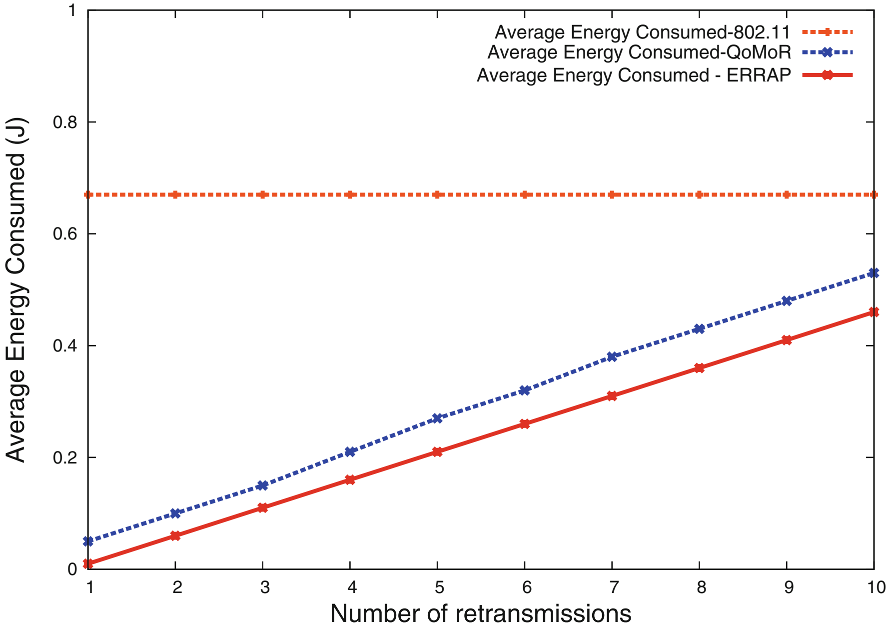


**Fig. 3.3** Average energy consumption of one-hop retransmission and comparison

### *3.8.3 Minimizing Energy Consumption*

The goal of *ERRAP* scheme is to minimize the energy consumption between any source node and the sink node. The lifetime of sensor nodes in the network is directly proportional to the energy dissipation of each sensor node. The consumed energy in sensors includes the energy required for sensing, transmitting, receiving and processing of data. *ERRAP MAC* scheme contribute to energy efficiency by minimizing collisions and retransmissions. We simulate the performance of *ERRAP* scheme with respect to energy consumption and compare the average energy consumption with *QoMoR* and *802.11b*.

The goal of the collision avoidance scheme is based on medium access control of the *ERRAP* to increase the channel access probability for fairly distributing the energy consumption of the stations and thereby increasing the network lifetime. Figure 3.3 shows the average energy consumption of the *ERRAP* scheme for different values of retransmissions with 2 K data packets when the aggregated data rate generated by all the nodes is about 50 Mbps, which is equal to the available bandwidth. The energy consumed by the *ERRAP* scheme for the number of retransmissions value 10, is less than the energy consumed by the *QoMoR* and *802.11b* protocol. The *ERRAP* scheme uses shorter frame slots, avoiding control packets like *RTS* and *CTS*, which unnecessarily consume energy and bandwidth.

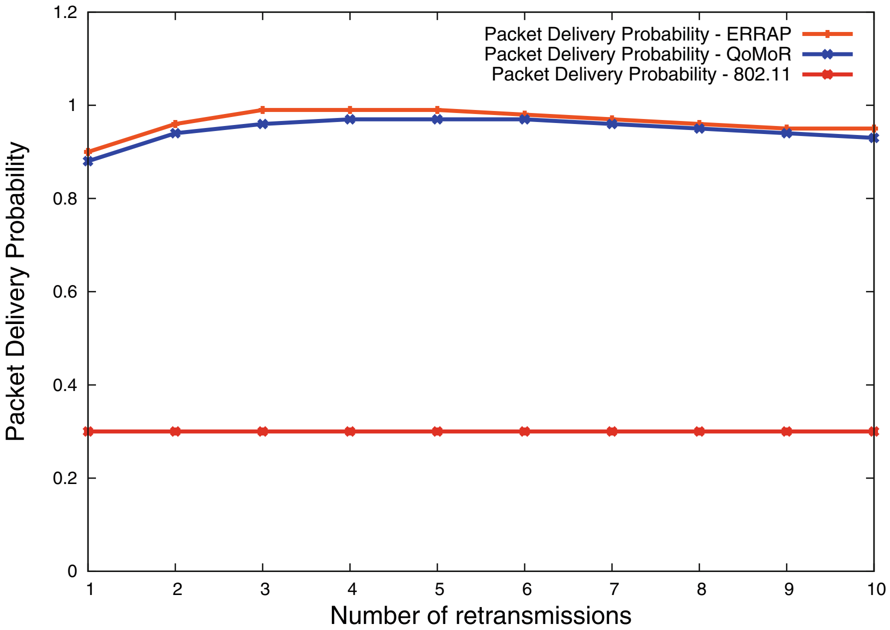


**Fig. 3.4** Packet delivery probability of one-hop retransmission and comparison

Figure 3.4 shows the packet delivery probabilities achieved by *ERRAP* scheme, *QoMoR* and *802.11b* under the same conditions. The *ERRAP* protocol is significantly higher than that achieved by the *QoMoR* and *802.11b* protocol. Both *QoMoR* and *802.11b* do not use the available bandwidth as efficiently as *ERRAP*. The *ERRAP* provides QoS to the nodes using random access mode where each node transmits data packet by selecting variable slots randomly for variable data packet according to the total number of sensors nodes and each node take local decisions, depending on some pre-defined efficient retransmission probabilities.

When the number of nodes is large and the aggregate data rate is matching the available channel bandwidth, the performance of the *ERRAP* scheme is significantly better than *QoMoR* and *802.11b* both in terms of *QoS*, delivery probability and energy consumption for the event-driven applications.

## 3.9 Conclusions

In this paper, we have designed and proposed an Efficient Retransmission Random Access Protocol (*ERRAP*) algorithm scheme which is a combination of collision avoidance and energy management for short-range, low-cost and low-energy WSN's applications like Smart Environment, Home Automation, Structure Monitoring, Intelligent Transportation and Medical Monitoring. In our work, we have assumed that the source nodes do not have receiver circuits. Hence, they can only transmit data packet to destination node, but cannot receive any acknowledgement control signals from destination. In *ERRAP* scheme, each source node simply retransmits each of its data packet an optimal number of times within a given period of time in one-hop QoS group. The source nodes employ probabilistic retransmission to minimize the energy consumption and maximize the packet delivery probability. In future work, we will focus on Two-QoS groups for both analytical and simulation to compare our scheme with other schemes.

## References

1. K. Jamieson, H. Balakrishnan, Y.C. Tay, *Sift: A MAC Protocol for Event-Driven Wireless Sensor Networks* (MIT Laboratory Computer Science, Cambridge, 2002)
2. W.Ye.J. Heidenmann, D. Estrin, Medium access control with coordinated adaptive sleeping for wireless sensor networks. IEEE/ACM Trans. Netw. **12**(3), 493–506 (2004)
3. H. Pai, J. Sung, Y.S. Han, Adaptive retransmission for distributed detection in wireless sensor networks, in *Proceedings of IEEE International Conference on Sensor Networks, Ubiquitious, and Trustworthy Computing*, vol. 2, Taichung, 2006, pp. 2–7
4. K. Lu, S. Fu, Y. Qian, Increasing the throughput of wireless LANs via cooperative retransmission, in *Proceedings of Globecom'07*, Washington, DC, 2007, pp. 5231–5235
5. L. Xiong, L. Libman, G. Mao, Optimal strategies for cooperative Mac-layer retransmission in wireless networks, in *Proceedings of IEEE Wireless Communications and Networking Conference*, Las Vegas, NV, 2008, pp. 1495–1500
6. J. Qureshi, C.H. Foh, J. Cai, An efficient network coding based retransmission algorithm for wireless multicast, in *Proceedings of IEEE Personal Indoor and Mobile Radio Communications*, Tokyo, 2009, pp. 691–695
7. J. Ruiz, J. Gallardo, L. Villasenor Gonzalez, D. Makrakis, H. Mouftah, QUATTRO: QoS-capable cross-layer MAC protocol for wireless sensor networks, in *Proceedings of IEEE Global Telecommunications Conference*, Honolulu, 2009, pp. 1–6
8. R.A. Tannious, A. Nosratinia, Cognitive radio protocols based on exploiting hybrid ARQ retransmissions. IEEE Trans. Wirel. Commun. **9**(9), 2833–2841 (2010)
9. J. Bai, E.P. Eyisi, Y. Xue, X.D. Koutsoukos, Dynamic tuning retransmission limit of IEEE 802.11 MAC protocol for networked control systems, in *Proceedings of 3rd IEEE/ACM International Conference on Cyber, Physical and Social Computing (CPSCom)*, Hangzhou, 2010, pp. 666–671
10. X. He, F.Y. Li, An optimal energy efficient cooperative retransmission MAC scheme in wireless networks, in *Proceedings of IEEE International Conference on Wireless Vehicular Technology, Information Theory, Aerospace and Electronic System Technology*, Chennai, 2011, pp. 1–5
11. T. Volkhausen, K. Dridger, H.S. Lichte, H. Karl, Efficient cooperative relaying in wireless multi-hop networks with commodity WiFi hardware, in *Proceedings of 10th IEEE International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt)*, Paderborn, 2012, pp. 299–304
12. Z. Wang, C. Li, Y. Chen, Local cooperative relay for opportunistic data forwarding in mobile Ad-hoc networks, in *Proceedings of IEEE International Conference on Communications (ICC)*, Ottawa, 2012, pp. 5381–5386
13. R.S. Sudhaakar, S. Yoon, J. Zhao, C. Qiao, A novel QoS-aware MAC scheme using optimal retransmission for wireless networks. IEEE Trans. Wirel. Commun. **8**(5), 2230–2235 (2009)