Adaptive Routing Mechanism for Real-Time Wireless Sensor Networks Based on Two-Hop Information

Sandhya Rachamalla and Anitha Sheela Kancherla

Abstract One of the critical and challenging aspects in wireless sensor networks (WSNs) is to optimally manage the limited energy of nodes without degrading the routing efficiency. In this paper, we propose an energy-efficient adaptive routing mechanism (EE-ARM) for WSNs which saves energy of nodes by removing the much delayed packets without degrading the real-time routing efficiency of the used routing protocol. It uses the adaptive transmission power algorithm which is based on the attenuation of the wireless link to improve the energy efficiency. Integrated in PATH, the well-known real-time routing protocol based on two-hop neighborhood information, the results show that the proposed routing mechanism perform good in terms of energy consumption per packet (ECPP) and deadline miss ratio (DMR).

Keywords Deadline miss ratio · Energy consumption per packet · Real-time routing · Adaptive transmission power

1 Introduction

Currently, WSNs are the latest research areas for the research community because of wide variety of applications that can be supported. Many WSN applications require real-time communication systems and examples of such applications can be found in many military areas, habitat monitoring, disaster management, and intelligent transportation systems [1]. Among several aspects of WSNs, energy conservation and delay, supporting real-time service is still gaining attention in research body [2]. Although efficient utilization of energy is the primary concern in WSNs

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for longer network lifetime; the low latency communication is also gaining importance in new applications. Out-dated information will be irrelevant, mainly in real-time environments and may lead to serious effects to the applied systems [3]. Timeliness is important in sending crucial messages in industrial WSNs. And sensor nodes are battery operated which have limited energy. Hence energy efficiency and latency are the important design goals in WSNs. Real-time QoS in WSNs can be addressed through different layers and mechanisms of the network [4]. Cross-layer optimization can provide further improvement in the performance of the network and above all, routing protocol design by the network layer plays an important role in supporting real-time QoS [3].

To reduce the complexity of the systems, most of routing protocols are based on one-hop neighborhood information [5]. However, multi-hop information-based routing can perform better as more information about the neighbors of a node in the network is available and that is effectively utilized in broadcast operations, channel access methods, etc. [6–8]. It is observed from the study that two-hop based routing results in less number of hops from source to sink when compared with that of one-hop based routing [6]. However, it is not attractive to go for three-hop based routing, as it further increases the complexity which may not be affordable for the given network application. Hence in this paper, the proposed routing mechanism is integrated with PATH, the well-known two-hop based real-time routing algorithm for WSNs. The rest of the paper is organized as follows Sect. 2 summarizes related routing protocols and their performance measures. Section 3 presents our proposed mechanism which aims to improve energy consumption and real-time QoS. The performance of the proposed protocol is evaluated in Sect. 4. Section 5 concludes the paper and possible enhancements are discussed.

2 Real-Time Routing Protocols for WSNs

Many researchers have provided solutions for real-time routing in WSNs. This section provides the analysis of the various existing real-time routing protocols for WSNs emphasizing their strengths and weaknesses and various other challenges. AODV [9] is a reactive, on-demand routing protocol which builds route between the nodes with sequence numbers, only when the source node demands for routing the sensed data. DSR [10] protocol is another on-demand routing protocol which eliminates the periodic updating of routing tables as it is *beacon-less.* RAP [11] is the first real-time communication architecture that handles the deadline issues pertaining to large scale WSNs. It uses the high level 'query and event' services and the *velocity monotonic scheduling* (VMS) policy to schedule packets.

SPEED [12] protocol is an important real-time communication protocol to route packets with the desired speed for sensor networks. It does not consider the energy parameter in forwarding metric and single speed is considered. MMSPEED [13] extends the SPEED protocol to support different velocities and level of reliability for multiple probabilistic QoS guarantee in two domains, *timeliness* and *reliability* in WSNs. RPAR [14] is the advance version of RAP. It is the first protocol that is designed to support the real-time routing for WSNs with power control. Application specific communication delays are handled in this protocol by adaptive transmission power and routing decisions are based on the system workload and packet deadlines. THVR [3] is a two-hop neighborhood information-based routing protocol for real-time WSNs proposed to support the QoS in terms of real-time packet delivery along with better energy efficiency. PATH [15] is another real-time protocol which uses the two-hop neighbor information for routing decisions. Dynamic adjustment of transmission power is adopted to reduce the packet dropping.

JiTS [16] shows that shortest path routing provides better performance than geographic routing and explores several policies for nonuniformly delaying data at several intermediate nodes for contention-free transmission. EARTOR [17] aims to increase the number of requests in the network and route requests are designed with specified latency constraints. Cross-layer design is adopted in EARTOR along with the routing mechanism at each relay node that takes into consideration remaining energy, position, and priority of relay node. EEOR [18] improves the throughput by allowing nodes that overhear the transmission to participate in forwarding the packet. The nodes are prioritized and low priority forwarder will discard the packet if the packet has been forwarded by high priority forwarder. The power control is done by sensors in the network using beacon messages and power loss is calculated in [19]. In [20], a two-hop based routing protocol is proposed with link reliability to reduce DMR with longer network lifetime. It implements the modules for estimating transmission delay and packet delivery ratios, but requires periodic update of these parameters with HELLO messages. In [21], packets are routed with differential delay constraints and reliability constraints along multiple paths, but one-hop neighborhood information is used.

In our proposed mechanism, we adopt the approach of identifying the slow packets, which are useless and cannot meet the prescribed deadline, and remove those packets from the queue of intermediate nodes located near to the sink. This conserves energy and improves the network lifetime. It also implements the adaptive transmission power algorithm, which dynamically changes the transmission power to be used in forwarding metric, instead of fixed transmission power as in THVR. Though power adaption scheme is used in PATH, it is invoked when it cannot find suitable two-hop neighbor and when it has sufficient choice of forwarding pair. During transmission, the power is adjusted according to the location of the receiver and the quality of the wireless link. This further improves energy efficiency. The forwarding metric is same as used in PATH, finding the suitable next forwarding pair based on the novel two-hop velocity integrated with energy balancing mechanism which maintains the routing efficiency without degrading the real-time behavior of the protocol. It is therefore named as energy-efficient adaptive routing protocol (EE-ARP). The proposed routing protocol details are given in the next section.

3 Design of EE-ARP for RT-WSN

The proposed protocol route the packets in three stages: (1) Identification and removal of much delayed packets (2) Adaptive transmission power algorithm and (3) Forwarding metric.

3.1 Identification and Removal of Much Delayed Packets

Not all the packets routed for transmission have the chance to reach their destination or sink within deadline. The deadline information is exploited in the proposed routing mechanism and the much delayed packets or slow packets are removed from the queue of intermediate nodes near the sink as it is useless to traverse those packets toward destination, thereby saving the energy of nodes. The queue is now maintained to have only packets with sufficient residual deadline. To identify the slow packet from the queue, EE-ARP calculates the expected delay for the current packet to reach the sink and decides whether to remove or not, the current packet based on this expected delay.

Expected Delay. The expected delay for the current packet p at the current node x to reach the destination d is $Txd(p)$ and is given by the formula (1).

$$Txd(p) = \frac{Dxd(p)}{Dsx(p)} * Tsx(p) \quad (1)$$

As shown in Fig. 1, $Dxd(p)$ denotes the remaining geographic distance that the current packet p has to traverse from current node x to the destination d and $Dsx(p)$ is the geographic distance traveled by the packet p from source s to current node x. $Tsx(p)$ gives the time delay for the packet to reach the current node x.

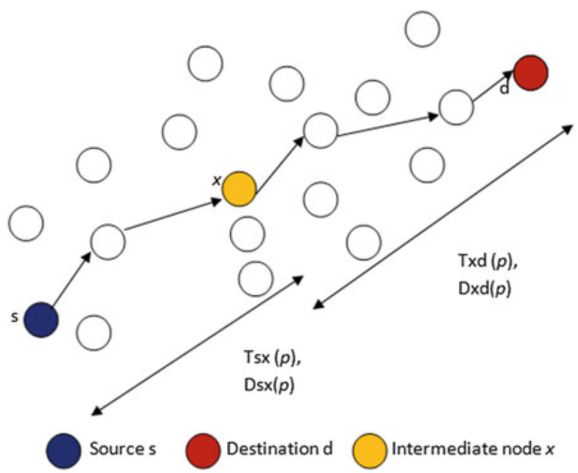

Fig. 1 Expected delay estimation

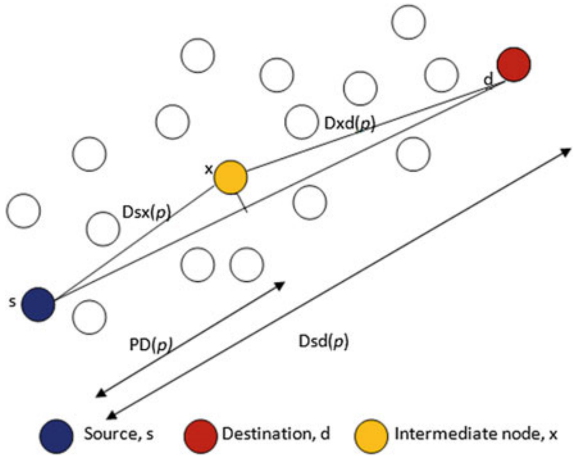

Fig. 2 Illustration of progressive distance PD(p)

3.2 Removal of Much Delayed Packets

After having the expected delay for the current packet p at current node x, it is to be decided whether the packet can be retained or not in the queue of intermediate node. The distance between the source s and the destination d, $Dsd(p)$ and progressive distance PD(p), the distance that the packet p progressed toward the destination, are used in the decision rule. Figure 2 shows the PD(p). The complete algorithm for the identification and removal of slow packets at each intermediate node is given in Algorithm 1.

The Algorithm 1 is as follows:

Algorithm 1 : Identification and Removal of slow packets

For each current packet p at the current node x,
Calculate expected delay $Txd(p)$
# **Packet removal decision rule.**
If $PD(p) > \alpha * Dsd(p)$ **then**
  If $Txd(p) > deadline\ (p)$ **then**
    Remove packet p from the queue of current node x
  Endif
Else
  If $\frac{PD(p)}{\alpha * Dsd(p)} * Txd(p) > deadline\ (p)$ **then**
    Remove packet p from the queue of current node x
  Endif
Endif

The PD(p) is calculated as shown in formula (2).

$$\mathrm{PD(p)} = \begin{cases} \frac{\mathrm{D^2sx(p)} - \mathrm{D^2xd(p)} + \mathrm{D^2sd(p)}}{2 * \mathrm{Dsd(p)}} & \text{if } \mathrm{Dsx(p)} < \mathrm{Dsd(p)} \\ \mathrm{Dsd(p)} & \text{otherwise} \end{cases} \quad (2)$$

The Algorithm 1 explains the procedure to identify and remove the unwanted slow packets from reaching the destination because of insufficient deadline and to preserve energy of the nodes by not forwarding them toward the destination. After calculating the expected delay as shown in formula (1), the packet removal decision rule is applied.

While simulating the proposed algorithm, the parameter α is chosen 0.5 where α is the parameter chosen according to the application, it must be close to 1 for real-time applications and close to 0 for energy-efficient applications. So, the packet is tested only when it is progressed more than 50 % of the total distance. If the packet p cannot meet the deadline requirement then it is removed from the queue of current node x. Otherwise, more chance is given to the packet p to reach the destination with $Txd(p)$ multiplied with $\frac{\mathrm{PD}(p)}{\alpha * Dsd(p)}$ and compared with given deadline. If the value exceeds the deadline, then the packet is removed.

3.3 Adaptive Transmission Power Algorithm

The queue of the current node now contains the useful packets after the removal of useless packets. The transmission power of each packet is adaptively varied based on the quality of wireless link and this power is used in forwarding metric for choosing the next candidate. In path loss model, the power transmitted from the transmitter falls as $1/d^n$, where d is the distance between the transmitter and receiver and n is the path loss exponent. This idea is exploited in the proposed routing mechanism. The adaptive transmission power algorithm is described in Algorithm 2.

Algorithm 2: Adaptive Transmission Power algorithm

1. While forwarding a packet p in a queue of intermediate node, the transmission power $P(x)$ is given by formula (3)

   $$P(x) = t.d^n + C \quad (3)$$

   where d is the distance from current intermediate node to the next forwarding node, n is the path loss exponent and depends on the quality of wireless link ($n \geq 2$). C is the system processing cost and t is prediction threshold.
2. The transmission energy $E(x)$ is given

   $$E(x) = P(x) * T(x) \quad (4)$$

   where $T(x)$ is the transmission time, the time required to send a packet by a node.

In the proposed routing protocol, the transmission power is varied based on the geographic position of next choice. During simulation, the path loss exponent n is chosen to be 2 and system processing cost C is assumed to be 0.

3.4 Forwarding Metric

The proposed routing mechanism is integrated with PATH [15] protocol and the same forwarding metric, which is based on velocity and energy metric, is used to select next forwarding pair for the packet p to get routed towards destination. But the transmission energies are adaptively calculated, as shown in formula (4), based on the distance between sender and receiver. This improves the energy efficiency and better forwarding pairs are selected in routing the packets.

4 Performance Evaluation

The EE-ARP is simulated in Network Simulator-2.35 [22]. We set the parameters close to practical WSN according to MicaZ motes [23] with MPR2400 (2.4 GHz) radio. Nodes are randomly deployed in a 500 m × 500 m sensing area and are fixed. We considered one source and one destination. The source node is chosen at the left-lower corner of the sensing area fixed at the location (95, 50 m), while the destination node is fixed at the location (43, 475 m) at right-top corner of the sensing area.

The EE-ARP is investigated and compared with THVR and PATH protocols. The source generates CBR traffic at 10 kbps rate with packet frame size 64 bytes (including header and CRC fields). The performance metrics are (i) ECPP, which is defined by the total energy expended divided by the number of successfully transmitted packets and (ii) DDMR, which is defined as the ratio of packets that miss the predefined deadline to the total transmitted packets. The deadline requirement is varied from 400 to 1,100 ms and in each run DMR is calculated for the three protocols. The results show that the proposed mechanism offers better energy efficiency than other two protocols as shown in Fig. 3. This is due to the adaptive transmission power algorithm and the novel method of removal of slow packets thereby saving the energy of nodes in the network.

The DMR is also improved in EE-ARP as shown in Fig. 4, because of the removal of much delayed packets at intermediate nodes and preventing them to reach the destination with large delay. In EE-ARP, the novel method of removal of much delayed packets is employed. This method helps in the removal of slow packets from the queue and only the packets which have sufficient residual deadline are retained for routing. Also the efficient utilization of energy results in better forwarding choice and the packets are routed effectively which further reduces DMR.

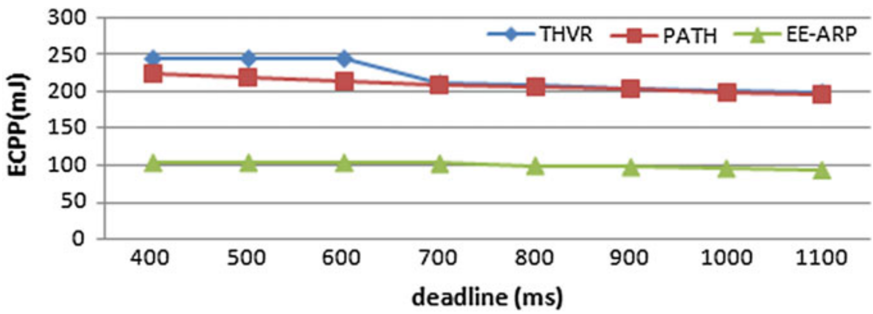

Fig. 3 ECPP comparison of THVR, PATH, and EE-ARP

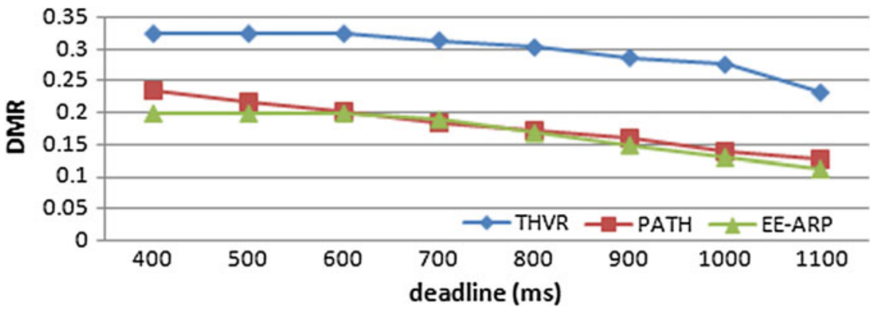

Fig. 4 DMR comparison of THVR, PATH, and EE-ARP

5 Conclusion and Future Scope

In this paper, an adaptive routing mechanism based on two-hop neighborhood information of the network is proposed. It employs a novel method of removal of much delayed packets and also the efficient adaptive transmission power algorithm to achieve better energy efficiency without degrading the real-time performance in WSNs. This integration reduces the energy consumption and improves DMR better than THVR and PATH. Our future work will consider multiple sources thereby increasing the traffic intensity in the network and the performance of the proposed mechanism is observed.

References

1. Chong CY, Kumar SP. “Sensor networks: evolution, opportunities, and challenges”, Proceedings of the IEEE. 2003 Aug; 91(8), pp. 1247–56.
2. Chen W, Li W, Shou H, Yuan B. “A QoS-based adaptive clustering algorithm for wireless sensor networks. In Mechatronics and Automation”, Proceedings of the 2006 IEEE International Conference on 2006 Jun 25 (pp. 1947–1952). IEEE.

3. Li Y, Chen CS, Song YQ, Wang Z, Sun Y. “Enhancing real-time delivery in wireless sensor networks with two-hop information”. Industrial Informatics, IEEE Transactions on. 2009 May; 5(2):pp 113–22.
4. Li Y, Chen CS, Song YQ, Wang Z, Sun Y. “A two-hop based real-time routing protocol for wireless sensor networks”. In Factory Communication Systems, 2008. WFCS 2008. IEEE International Workshop on 2008 May 21 (pp. 65–74). IEEE.
5. Li Y, Chen CS, Song YQ, Wang Z. “Real-time QoS support in wireless sensor networks: A survey”. In 7th IFAC International Conference on Field buses & Networks in Industrial & Embedded Systems-FeT’2007, 2007.
6. Shue Chen C, Li Y, Song YQ. “An exploration of geographic routing with k-hop based searching in wireless sensor networks”. In Communications and Networking in China, China Com 2008. Third International Conference on 2008 Aug 25 (pp. 376–381). IEEE.
7. Spohn MA, Garcia-Luna-Aceves JJ. “Enhancing broadcast operations in ad hoc networks with two-hop connected dominating sets”. In Mobile Ad-hoc and Sensor Systems, 2004 IEEE International Conference on 2004 Oct 25 (pp. 543–545). IEEE.
8. Calinescu G. “Computing 2-hop neighborhoods in ad hoc wireless networks.” In Ad-Hoc, Mobile, and Wireless Networks 2003 Jan 1 (pp. 175–186). Springer Berlin Heidelberg.
9. C.E. Perkins, E.M. Royer, “Ad hoc On-Demand Distance Vector Routing,” Proc. of 2nd IEEE Workshop on Mobile Computing Systems and Applications, New Orleans, LA, February, 1999, pp 90–100.
10. David B. Johnson, David A Maltz, Josh Broch “DSR: The dynamic source routing protocol for multihop wireless adhoc networks”, in Mobile Computing, Chapter 5, pp 153–181, Kluwer Academic publishers, 1996.
11. C lu, B. M. Blum, T.F. Abdelzaher, J.A. Stankonic and T. He, “RAP: A real time Architecture for large scale wireless sensor networks,” in proceedings of RTA S, 2002, September, 2002.
12. Tian He, John A Stancovic, Chenyang Lu, Tarek Abdelzaher,” Speed: A Stateless protocol for real time Communication in Sensor network”, Proceedings of International Conference on Distributed Computing systems, Providence, RI, May 2003.
13. Emad Felemban, Chang Gun lee and Eylem Elcici, “MM SPEED: Multipath Mulit-speed protocol for QoS guarantee of reliability and Timeliness in Wireless sensor networks”, IEEE transactions on Mobile computing [J], pp 738–754, 2006.
14. O. Chipura, Z. He, G. Xing, Q. Chen, Xiaorui Wang, C. Lu, J. Stankovic, T. Abdelzaher, “Real time Power Aware Routing Protocol in Sensor networks”, in the proceedings of IWQoS 2006, June 2006.
15. P. Rezayat, M. Mahdavi, M. Ghasemzadeh, Agha. S, “A Novel Real time Power Aware Routing Protocol”, in the proceedings of IJCSNS, Vol 10, April, 2010.
16. Liu K, Abu-Ghazaleh N, Kang KD. “JiTS: Just-in-time scheduling for real-time sensor data dissemination.” In Pervasive Computing and Communications, 2006. PerCom 2006. Fourth Annual IEEE International Conference on 2006 Mar 13 (pp. 5-pp). IEEE.
17. Yang W, Liang W, Dou W. “Energy-aware real-time opportunistic routing for wireless ad hoc networks.” InGlobal Telecommunications Conference (GLOBECOM 2010), 2010 IEEE 2010 Dec 6 (pp. 1–6). IEEE.
18. Mao X, Tang S, Xu X, Li XY, Ma H. “Energy-efficient opportunistic routing in wireless sensor networks.” Parallel and Distributed Systems, IEEE Transactions on. 2011 Nov; 22 (11):1934–1942.
19. Trung Dung Nruyen, Van Duc Nruyen, Tien Pham Van, Wakasugi Koichiro and Ngoc Tuan Nguyen,” Power Control Combined with Routing protocol for Wireless Sensor Networks”, Computing, Management and Tele-communications (ComManTel), April, 2014.
20. Shiva, Prakash T., et al. “Link-reliability based two-hop routing for QoS guarantee in Wireless Sensor Networks.” Wireless Personal Multimedia Communications (WPMC), 2013 16th International Symposium on. IEEE, 2013.

21. Rachamalla, Sandhya, and Anitha Sheela Kancharla. "Power-Control Delay-aware routing and MAC protocol for Wireless Sensor Networks." Networking, Sensing and Control (ICNSC), 2015 IEEE 12th International Conference on. IEEE, 2015.
22. Network Simulator: http://www.isi.edu/nsnam/ns.
23. Crossbow Motes, http://www.xbow.com.