

# A Power-Aware Real-Time Routing Mechanism for Wireless Sensor Networks

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**Abstract**— To optimally manage the limited energy of nodes without degrading efficiency of routing protocols in delivering real-time packets in wireless sensor networks, we propose in this paper an efficient power-aware real-time routing (PRR) mechanism. Firstly, it increases the network fluidity and saves more energy of nodes by removing early in network all useless data packets according to their residual deadline and expected end-to-end delay. Secondly, it reinforces the real-time behavior of the used routing protocol and preserves the network resources by selecting from the current-node queue the most urgent packet to be forwarded first. Finally, it saves energy of nodes without degrading the protocol efficiency in delivering real-time flows by combining adjusted transmission power of current node with relay speed of the forwarding candidate neighbors when selecting a next forwarder for the current packet. PRR is simple to implement and can be easily integrated in any geographic routing protocol. Associated with the well-know real-time routing protocol SPEED by using TinyOS, and evaluated in its embedded simulator TOSSIM, PRR achieved good performance in terms of network energy consumption, packet loss ratio, and node energy balancing.

**Keywords**— *wireless sensor networks; real-time routing; energy-aware routing; node energy balancing.*

## I. INTRODUCTION

Flexibility, fault tolerance, reduced production cost, high capture capacity, and rapid installation are characteristics that enabled a wireless sensor network (WSN) to have multiple application domains, such as disasters detection and monitoring, mapping biodiversity, intelligent building, precision agriculture, machinery monitoring and preventive maintenance, environmental control, logistics and intelligent transportation, and medicine. However, the WSN realization requires satisfaction of some constraints that arise from a number of factors guiding the design phase, such as fault tolerance, scalability, cost, durability, material and topology.

WSNs are often characterized by a dense and large scale deployment with limited processing, storage, transmission and energy resources. It is recognized that conserving energy is an unavoidable issue in the design of WSNs because it imposes strict constraints on network operations [1-3]. In fact, the energy consumed in sensor nodes has an important impact on network lifetime that has become the dominant performance criterion. Extending lifetime of a WSN is a shared objective by designers and researchers. It is necessary that routing algorithms use paths that save more energy of nodes.

Although existing works [4-12], summarized in Section II, play important roles in improving network performance, design of energy-aware real-time routing protocols is still a challenging area in WSNs. To contribute in this domain, we propose in this paper an efficient power-aware real-time routing (PRR) mechanism which:

- Increases the network fluidity and saves more energy of nodes by removing early in the network all useless packets according to their residual deadline and expected end-to-end delay.
- Reinforces the real-time behavior of the used routing protocol and preserves the network resources by selecting from the current-node queue the most urgent packet to be forwarded first.
- Saves energy of nodes without degrading the protocol efficiency in delivering real-time flows by combining adjusted transmission power with relay speed of the forwarding candidate neighbors when selecting a next forwarder.

The rest of the paper is organized as follows. Section II summarizes the related works. Section III describes the proposed PRR mechanism that aims to improve efficiency of real-time routing protocols based on geographic location of sensor nodes. Section IV evaluates and discusses performance of our proposal. Section V concludes the present paper.

## II. RELATED WORKS

Some existing real-time routing protocols don't consider explicitly the limited energy of sensor nodes [4-8]. RAP [4] is one of the earlier real-time routing protocols for WSNs. It provides service differentiation in the timeliness domain by using velocity-monotonic classification of data packets. It works only when most traffic is periodic and all periods are known previously. Also, it is not adaptable to dynamics of a network. SPEED [5] is designed to be a stateless, localized algorithm with minimal control overhead. It achieves an end-to-end soft real-time communication by maintaining a desired delivery speed across the sensor network through a novel combination of feedback control and stateless non-deterministic geographic forwarding. MMSPEED [6] extends SPEED to support different delivery velocities and levels of reliability. It provides QoS differentiation in two quality domains, namely, timeliness and reliability, so that

packets can choose the most proper combination of service options depending on their timeliness and reliability requirements. THVR [7] adopts, like SPEED, the approach of mapping packet deadline to a velocity, which is known as a good metric to delay constrained packet delivery. However, its routing decisions are based on two-hop neighborhood information to achieve lower end-to-end deadline miss ratio and higher energy utilization efficiency. DMFR [8] routes data packets in five stages: initialization, packet transmission, jumping transmission, jumping probability adjustment and transmission finish. Transition from transmission stage to jumping stage occurs when a node is congested. To reduce the packet loss ratio, each sensor node dynamically adjusts its jumping probabilities.

However, some of other existing routing protocols use specific mechanisms to save energy of sensor nodes and/or to maximize the sensor network lifetime [9-12]. PATH [9] improves real-time routing performance by means of reducing the packet dropping in routing decisions. It is based on the concept of using two-hop neighbor information and power-control mechanism. The former is used for routing decisions and the latter is deployed to improve link quality as well as reducing the delay. The protocol dynamically adjusts transmitting power in order to reduce the probability of packet dropping and addresses practical issue like network holes, scalability and loss links in WSNs. EARTOR [10] is designed to route requests with specified end-to-end latency constraints, which strikes the elegant balance between the energy consumption and the end-to-end latency and aims to maximize the number of the requests realized in network. The core techniques adopted include the cross-layer design that incorporates the duty cycle, a bidding mechanism for each relay candidate that takes its residual energy, location information, and relay priority into consideration. EEOR [11] improves the sensor network throughput by allowing nodes that overhear the transmission and closer to the sink to participate in forwarding the packet, i.e., in forwarder list. The nodes in forwarder list are prioritized and the lower priority forwarder will discard the packet if the packet has been forwarded by a higher priority forwarder. One challenging problem is to select and prioritize forwarder list such that the energy consumptions by all nodes is optimized. Extensive simulations in simulator TOSSIM show that this protocol performs well in terms of energy consumption, packet loss ratio, and average delivery delay. TREE [12] is a routing strategy with guarantee of QoS for industrial wireless sensor networks by considering the real-time routing performance, transmission reliability, and energy efficiency. By using two-hop information, real-time data routes with lower energy cost and better transmission reliability are used in the proposed routing strategy.

### III. PROPOSED POWER-AWARE MECHANISM

The proposed PRR mechanism routes data packets in three stages: useless packet remove (Section III-A), urgent packet selection (Section III-B) and next forwarder selection (Section III-C). Note that the calculus are done locally in the

current node and the used information is either in the received packet to forward, such as previous hops' delay, geographic location of source and destination nodes, or inside the current node, such as its geographic location and those of its neighbors.

#### A. Useless packet remove

Many real-time routing protocols [4-12] forward, often over long distances, packets that have no chance to reach their destination because of its insufficient deadline. This is because the packet deadline information, which is important in this type of applications, is not exploited by these protocols. To save more energy of nodes, the proposed PRR mechanism ensures an early removal of any useless packet because it will not reach its destination. Indeed, only packets with sufficient residual deadline to reach the sink node are forwarded in network. Also, PRR increases the network fluidity and reinforces the real-time aspects of the routing protocol. To do this, PRR calculates the expected end-to-end delay allowing the current packet to reach its destination node, then decides whether to remove or not the current packet depending on both this expected end-to-end delay and constant threshold  $\alpha$  related to application requirements in which the removal of delayed packets is performed.

1) *Expected end-to-end delay*: As shown in Figure 1, current node  $i$  calculates the expected end-to-end delay  $T_{id}(p)$ , allowing current packet  $p$  to reach its destination  $d$ , by using Formula (1). In this formula,  $T_{si}(p)$  denotes the previous hops' delay since source node  $s$ ,  $D_{si}(p)$  is the geographic distance traveled by packet  $p$  until current node  $i$ ,  $D_{id}(p)$  is the remaining geographic distance to reach  $d$ .

$$T_{id}(p) = \frac{D_{id}(p)}{D_{si}(p)} * T_{si}(p) \quad (1)$$

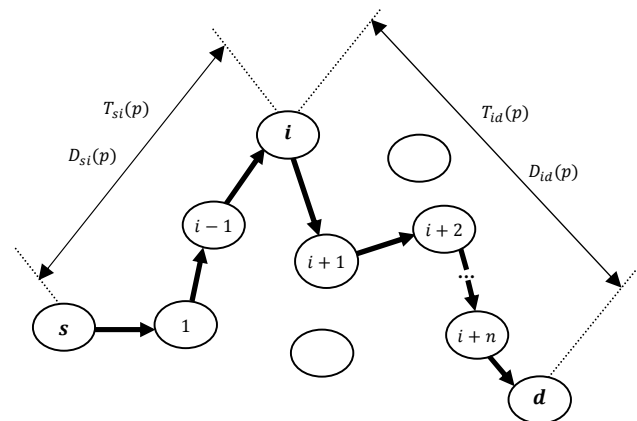


Figure 1. Expected end-to-end delay estimation.

2) *Packet remove decision*: Having the expected end-to-end delay  $T_{id}(p)$  and to decide whether to remove or not packet  $p$ , current node  $i$  applies the decision rule shown in Figure 2, where  $D_{sd}(p)$  is distance between source node  $s$  and destination node  $d$ ,  $AD(p)$  is the advance in distance of data packet  $p$  toward its destination which is given by

Formula (2) and shown in Figure 3, and  $\alpha$  is a constant parameter set in the interval  $[0,1]$  according to the application requirement. The value of  $\alpha$  must be close to 0 for energy-critical applications to maximize the network lifetime or close to 1 for time-critical applications to minimize the packet loss ratio.

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IF  $AD(p) > \alpha * D_{sd}(p)$  THEN
  IF  $T_{id}(p) > Deadline(p)$  THEN Remove packet  $p$ ; ENDIF
ELSE
  IF  $\frac{AD(p)}{\alpha * D_{sd}(p)} T_{id}(p) > Deadline(p)$  THEN Remove  $p$ ; ENDIF
ENDIF
    
```

Figure 2. The packet remove decision algorithm.

The packet decision remove algorithm (Figure 2) is explained as follow. If  $AD(p)$  is greater than  $\alpha * D_{sd}(p)$  then node  $i$  removes each delayed packet after the distance threshold  $\alpha * D_{sd}(p)$ . Otherwise,  $T_{id}(p)$  is multiplied by  $AD(p) / (\alpha * D_{sd}(p))$  to give more chance to current packet  $p$  to advance in network. If the result exceeds  $Deadline(p)$  despite the given chance then packet  $p$  is removed to save the energy of nodes and to increase the network fluidity. In our simulations given in Section IV parameter  $\alpha$  is set at 0.5. Thus, each delayed packet  $p$  with an advance  $AD(p)$  greater than 50% of the total distance  $D_{sd}(p)$  is immediately removed by current node  $i$  in order to increase fluidity of links and to save resources of sensor nodes.

$$AD(p) = \begin{cases} \frac{D_{si}^2(p) - D_{id}^2(p) + D_{sd}^2(p)}{2D_{sd}(p)} & \text{IF } D_{si}(p) < D_{sd}(p) \\ D_{sd}(p) & \text{OTHERWISE} \end{cases} \quad (2)$$

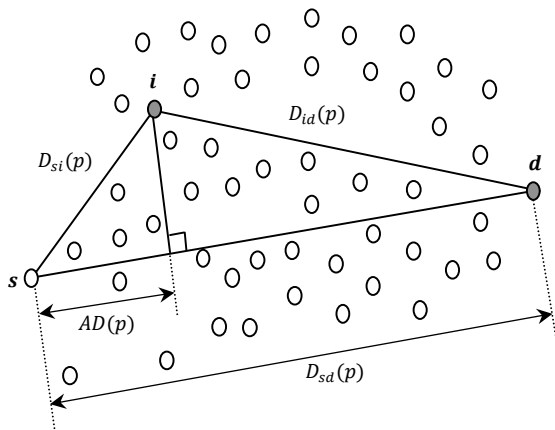


Figure 3. Advance in distance estimation.

### B. Urgent packet selection

Most existing real-time routing protocols use scheduling schemes based only on residual deadline of a data packet to forward [13]. However, these schemes may not be effective

when packets are sent to different destinations; case of a network using several sinks. In fact, these schemes give forwarding priority to a packet whose deadline is the smallest although it is very close to its destination. In the example shown in Figure 4, node  $i$  has two packets to forward:  $p_1$  for destination  $d1$  with 2 ms (milliseconds) as deadline and  $p_2$  for destination  $d2$  with 3 ms as deadline. According to existing scheduling schemes based on residual deadline, node  $i$  will firstly forward packet  $p_1$  and then probably causes the removal of packet  $p_2$  because of its distance to destination  $d2$ . The proposed PRR mechanism provides an efficient solution to this problem because it performs as follows:

- For each data packet  $p_j$  in the queue of current node  $i$ , calculate the decision parameter  $D(p_j)$  by Formula (3), where  $T_{id}(p_j)$  is the expected end-to-end delay, obtained by Formula (1), allowing packet  $p_j$  to reach its destination  $d$ .
- Selects data packet  $p_k$  having the smallest decision parameter  $D(p_k)$  by running Function (4).

$$D(p_j) = Deadline(p_j) - T_{id}(p_j) \quad (3)$$

$$D(p_k) = Min \{ D(p_j); \forall p_j \in Queue(i) \} \quad (4)$$

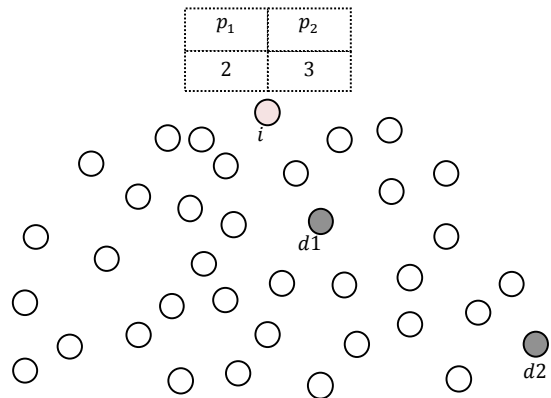


Figure 4. Most urgent packet selection by current node  $i$ .

Then, in the PRR mechanism, the two packets  $p_1$  and  $p_2$  (Figure 4) will probably reach their respective destination before their deadline expires because current node  $i$  will forward packet  $p_2$  before packet  $p_1$ . Note that PRR is also valid for a network using one destination node (sink).

Note that the most urgent packet selection can be done in two ways: a) during the packet reception by a node where its queue is scheduled according to Formula (3) or b) during the forwarding process where the most urgent packet is timely chosen from the queue. In way (a), PRR minimizes calculations but loses reliability because the queuing delay of packet  $p_j$  is not considered when estimating its  $T_{id}(p_j)$ . But in way (b), the current-node queue is not scheduled and selection of the most urgent packet requires extraction of all packets belonging to this queue. Since PRR is designed to

achieve lower loss ratio and to reduce energy consumption, way (b) has been implemented in our proposal, where a current node applies both the decision rule (Figure 2) and Function (4) on all packets in its queue in order to remove each delayed packet and to select the most urgent packet among the not delayed packets.

### C. Next forwarder selection

Radio range adjustment has become possible in recent sensor nodes. The quantity of energy required to send a message is proportional to the transmission power used by the sender node [14]. Since the attenuation of the radio power of a wireless link is usually proportional to the square of the distance between the sender and the receiver, the proposed PRR mechanism uses this idea. Indeed, PRR adjusts the sender transmission power according to location of receiver node in order to reduce energy consumed during the routing process.

A power-based algorithm tries to minimize the quantity of power required to route a message between source and destination nodes. The most commonly used energy model [15] calculates by using Formula (5) the energetic cost of a message forwarded by node  $u$  to node  $v$ , that are separated by distance  $d_{uv}$ , by. In this formula, constant parameters  $\alpha$  and  $c$  depend on the network environment:  $c$  represents the signal processing cost and  $\alpha$  is the signal attenuation ( $\alpha \geq 2$ ). In our performance evaluation in Section IV, we have  $\alpha=2$  and  $c=0$ . The optimal cost of a link in terms of energy consumption is that minimizes Formula (5); a function that does not consider any real-time service.

$$Power(uv) = \begin{cases} d_{uv}^\alpha + c & \text{IF } d_{uv} \neq 0 \\ 0 & \text{OTHERWISE} \end{cases} \quad (5)$$

The same definition of  $FS$  (Forwarding candidate neighbors Set) introduced in SPEED (Figure 5) is used in our proposal, but an improved forwarding strategy has been proposed. In SPEED, the next forwarder of current packet  $p$  toward destination node  $d$  is selected by current node  $i$  from its  $FS$ , which is constructed from its  $NS$  (Neighbors Set), according to a relay speed metric. Node  $n_i$  is a forwarding candidate neighbor if  $distance(n_i, d) < distance(i, d)$ . In Figure 5, we have:  $NS = \{n_1, n_2, n_3, n_4, n_5, n_6, n_7\}$  and  $FS = \{n_1, n_2, n_3\}$ . The relay speed provided by a neighbor  $n_i$  in  $FS$  is given in SPEED by Formula (6), where  $L$  is distance between node  $i$  and destination  $d$ ,  $L_{next}$  is distance between neighbor  $n_i$  in  $FS$  and destination  $d$ , and  $HopDelay(n_i)$  is the estimated delay of link  $(i, n_i)$ .

$$S(n_i) = \frac{L - L_{next}}{HopDelay(n_i)} ; n_i \in FS \quad (6)$$

To make SPEED energy-aware with high reliability in forwarding real-time flows, Formula (5) cannot be applied directly in PRR because our objective is to achieve lower packet loss ratio and higher energy utilization efficiency. To do this, PRR considers all neighbors in  $FS$  of current node  $i$  to select the next forwarder of current packet  $p$ . PRR

combines the transmission power  $P(n_i)$  required in node  $i$  to reach a neighbor  $n_i$  in  $FS$ , given by Formula (5), with the relay speed  $S(n_i)$  of  $n_i$ , given by Formula (6). Neighbor  $n_k$  with the higher decision parameter  $D(n_i)$  is selected by node  $i$  as next forwarder. Formally, node  $i$  applies Function (7), where  $D(n_i)$  is given by Formula (8).

$$NextHop(p) = n_k ; \text{ with } : D(n_k) = Max \{ D(n_i) ; \forall n_i \in FS \} \quad (7)$$

$$D(n_i) = \frac{S(n_i)}{P(n_i)} ; n_i \in FS \quad (8)$$

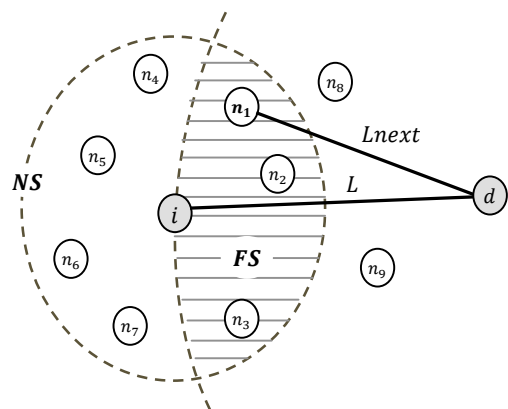


Figure 5. The sets  $NS$  and  $FS$  of a current node  $i$  in SPEED.

## IV. PERFORMANCE EVALUATION

To evaluate performance of the PRR mechanism, we associate it with the well-known real-time routing protocol SPEED [5] and the resulting protocol is called PA-SPEED (Power-Aware SPEED). We change in SPEED only the SNGF (Stateless Nondeterministic Geographic Forwarding) component. In the PA-SPEED protocol, when a node has to forward a data packet it first removes all delayed packets from its queue, then selects the most urgent packet among the not delayed packets and finally forwards the selected urgent packet to the neighbor realizing the best tradeoff between transmission power and relay speed.

The protocols SPEED and PA-SPEED have been implemented in TinyOS [16] and evaluated in its embedded sensor network simulator TOSSIM [17]. Also, the recent existing routing protocol EEOR [11] has been evaluated in this simulator and in the same conditions. Since we are interested by real-time applications, we used a scenario of detecting events that occur randomly in a field. Once an event is detected, the information captured will be forwarded in a required deadline toward a sink which is usually connected to an actuator.

Our simulation scene uses a uniform random distribution of sensor nodes. We perform simulations on a terrain with size  $500 \times 500$  meters and 625 deployed sensor nodes (with 12 neighbors per node as density). Two destination nodes are deployed and each one receives packets concerning particular event detection. At each time period, 20 randomly source nodes, equitably distributed on each side of the network, detect an event and forward corresponding

information to one destination node (sink). Each simulation runs during 230 seconds. Parameters used in our simulations are given in TABLE I.

For each simulation, we set the packet deadline to 500 ms (milliseconds), we vary the source rate from 3 to 23 pps (packets per second) and we measure the performance of SPEED [5], EEOR [11] and PA-SPEED in terms of packet loss ratio, energy consumed per delivered packet, and energy balancing factor (*ebf*). The later represents variance in energy consumed by all sensors with the same initial energy. Formally,  $ebf = (1/ns) * \sum_{k=1}^{ns} (ec_k - ec_{avr})^2$ , where  $ec_k$  is the energy consumed by sensor  $k$  and  $ns$  is the number of deployed sensors,  $ec_{avr}$  is the average energy consumed by all deployed sensors.

TABLE I. SIMULATION PARAMETERS.

MAC layer	CSMA-TinyOS
Radio layer	CC2420 radio layer
Propagation model	log-normal path loss model
Queue size	50 packets
Transmission channel	WirelessChannel
Bandwidth	200 Kilobytes per second
Packet size	32 bytes
Energy model	PowerTOSSIMz model
Node radio range	40 meters

The obtained simulation results, given in the figures 6-8, show that the PRR mechanism, used in the PA-SPEED protocol, is efficient in terms of delivering real-time flows and managing energy of sensor nodes.

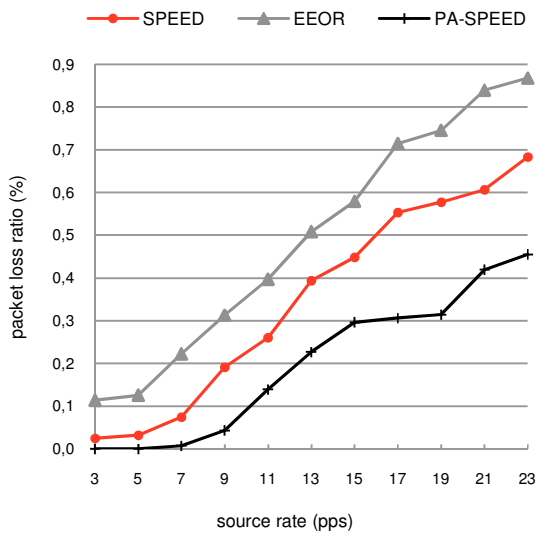


Figure 6. Success in delivering real-time packets.

Indeed, PA-SPEED loses less data packets (Figure 6) and consumes less energy of sensor nodes (Figure 7) than the protocols EEOR and SPEED. This is due to the PRR mechanism which first increases the network fluidity and saves energy of nodes by removing each packet having less chance to reach its destination according to its residual

deadline and expected end-to-end delay, then reinforces the real-time behavior of the PA-SPEED protocol by selecting from the current-node queue the most urgent packet among the not delayed packets to be forwarded first, and finally forwards the selected urgent packet to the neighbor realizing the best tradeoff between transmission power of the current node and relay speed of the next forwarder neighbor. In application with high rate, the protocols EEOR and SPEED lose more packets because the deadline information is not used in their routing decisions.

Figure 8 shows that PA-SPEED outperforms SPEED and EEOR in balancing energy of nodes. This performance is due to the PRR mechanism which uses the SPEED load balancing metric, i.e. relay speed given in Formula (6), which is based on a hop delay estimation representing the links' fluidity.

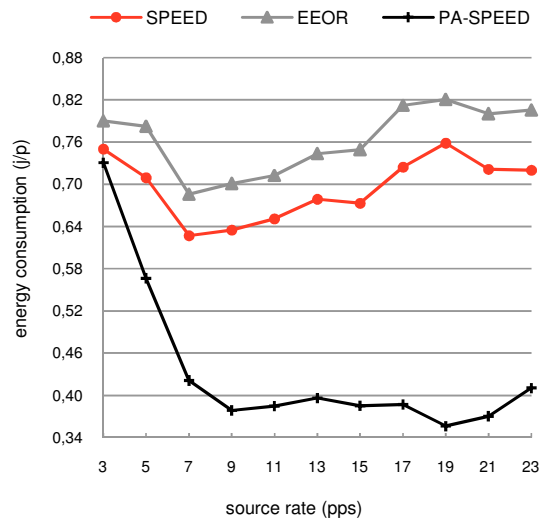


Figure 7. Average energy consumed per delivered packet.

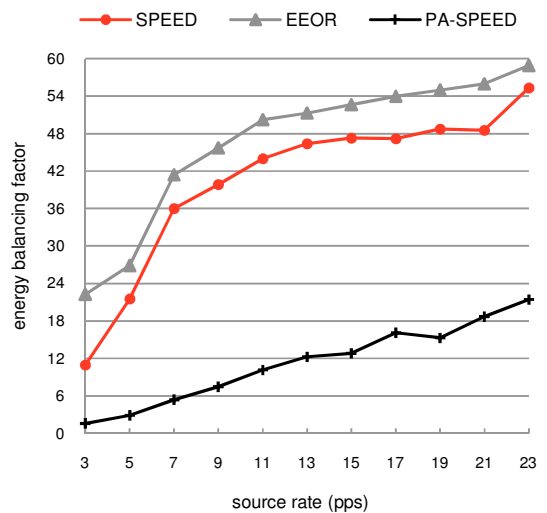


Figure 8. Performance in node energy balancing.

## V. CONCLUSION

An efficient mechanism (PRR) that aims to improve energy managing and to deliver maximum real-time packets in wireless sensor networks has been proposed in this paper. In this power-aware mechanism, the current node removes from its queue all delayed packets to increase links' fluidity and to save nodes' energy, then selects from the list of not delayed packets the most urgent packet according to residual deadline and expected end-to-end delay to satisfy real-time application constraints, and finally, forwards the selected urgent packet to the neighbor realizing the best tradeoff between transmission power and relay speed.

Then, we have associated the PRR mechanism with the existing SPEED real-time routing protocol and the obtained protocol (PA-SPEED) has achieved good performance in terms of packet loss ratio, energy consumed per delivered packet, and node energy balancing.

Since we base dropping decisions concerning delayed packets simply on estimated travel times towards the sink, our future work will consider any kind of weights, urgencies, fairness, or importance values of packets in order to have a less aggressive approach. We also plan to put our source codes in Imote2 sensor nodes for experimental tests in order to consolidate the simulation results presented in the present paper.

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