

# Power Aware Differentiated Routing (PADR) in Wireless Sensor Networks

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**Abstract**—We analyze routing algorithm for wireless sensor networks called Power Aware Differentiated Routing (PADR), which is proposed for collaborative routing of Real-time (RT) and Non-real time (NRT) traffic in a sensor field in order to prolong the otherwise shorter life time of RT sensor network. PADR uses nodes in the non-real time network as backup for routing RT traffic. It involves swapping a forwarding node for RT traffic from a node with critical minimum power level to the node with the best power level (often from a node in RT network to a node in NRT network). We derive analytical expressions for life time of RT and NRT networks under PADR routing protocol. The numerical results show that the performance of PADR depends on the remaining power of sensor nodes during route swapping. The results also show that PADR can increase the life time of RT network by up to 50%, and that similar reduction level of life time is incurred to NRT network.

**Keywords** - Wireless sensor networks, Power aware routing, Differentiated routing, Network life time, Real-time traffic

## I. INTRODUCTION

A wireless sensor network (WSN) consists of a number of microelectronic devices called sensor nodes (SNs) with sensing, data processing, and communications capabilities for monitoring a particular physical environment. Sensor nodes are typically deployed in random fashion in a specific geographic area, called a *sensor field*.

Sensor networks have potential applications in a wide variety of areas such as in military, health and security [4], [2] for either environmental data collection, security monitoring, or sensor node tracking. Examples of specific applications include early forest fire detection, sophisticated earthquake monitoring, battlefield surveillance, and highly specialized medical diagnostic tasks.

Data collected by individual sensor nodes can be categorized either as Real-time (RT) or Non-real time (NRT) nodes depending on the type of application the network is tailored for sensing. Example of RT applications where sensor networks can be deployed include real time traffic monitoring and monitoring enemy movements in a battle field. Examples of NR applications include temperature, rainfall, noise level, pollution, and humidity.

Real-time data is time critical, meaning it is constrained by stringent deadlines, whereas Non-real time data is not time critical, which is tolerant to network delays. Consequently, we

also call a WSN that captures real-time environmental data as real-time WSN otherwise we call it a Non-real time WSN. The performance of a WSN in terms of its *life time* heavily depends on the type of data the WSN captures and forwards. RT WSNs often generate data at much higher rate than NRT WSNs and thus RT WSNs are known to have shorter life times than NRT WSNs.

In this paper, we address the issue of limited energy in WSNs through designing power aware routing in a sensor field with heterogeneous WSNs, namely RT and NRT WSNs. We assume that the two networks can collaborate in order to improve the network life span which we call *netlife time* of RT WSN without reducing the netlife time of NRT WSN too much. This can be achieved by a routing algorithm that differentiates the choice of the next hop node on the path based on the type of the data (RT or NRT) and the remaining power on the next hop nodes.

A number of previous work have considered transmission of RT data [7], [3], [8]. In general these previously proposed solutions assume deadlines are set for RT data and the main objective becomes to ensure that RT data packets reach destination within their deadlines. In contrast to this work, the mentioned previous work don't focus on collaboration of heterogeneous WSNs. Specific example is Real-Time Power-Aware Routing in Sensor Networks (PRAR) presented [3]. PRAR dynamically adapts transmission power and routing decisions based on the packet deadlines. Although the work focused on real-time applications with the assumption that meeting the deadlines of critical data is more important than the total throughput, it should be noted that achieving the maximum possible throughput for NRT traffic is equally important. The primary goal of PRAR was to increase the number of packets that meet their deadlines while minimizing the energy consumed for transmitting packets under their deadline constraints. It focused on minimizing the energy consumed in packet transmissions. The proposed PADR differs from PRAR in that PADR doesn't use a power adaptation scheme.

The remainder of the paper is organized as follows: We formulate network model in Section II. In Section III we derive expressions for node life time, whereas in Section IV we present analysis of network life time of RT and NRT networks under PADR and present numerical results. We then briefly

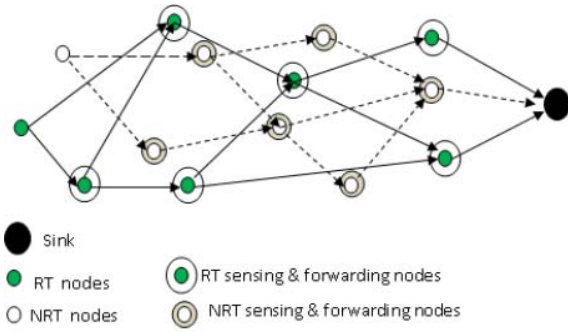


Fig. 1. RT and NRT WSNs in the same sensor field

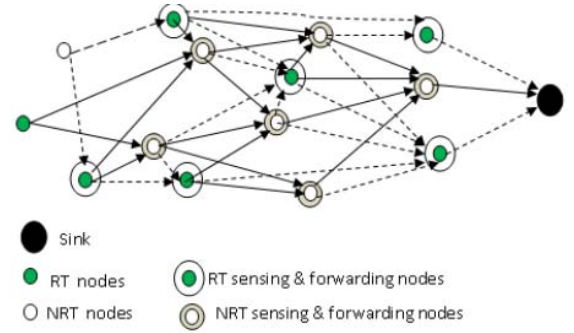


Fig. 2. Collaborating RT and NRT WSNs

discuss a possible PADR algorithm and requirements for its implementation in Section V, and finally summarize findings of the work in Section VI.

## II. PADR NETWORK MODEL

Most previous research works have considered homogeneous WSNs where a network is deployed to monitor one environmental condition. A homogeneous WSN is composed of a set of  $|\mathcal{N}|$  homogeneous nodes such that  $\mathcal{N} = \{n_i\}, i = 1, 2, \dots, |\mathcal{N}|$ . In this work, we consider a scenario where heterogeneous WSNs are placed in the same sensor field to capture different physical phenomena. Specifically we consider the case where one WSN is deployed for RT and the other is for NRT sensing (see illustration in Fig. 1).

Let's denote RT and NRT WSNs as  $\mathcal{N}_{rt} = \{n_{rt,i}\}$  and  $\mathcal{N}_{nrt} = \{n_{nrt,j}\}$  respectively where  $n_{rt}$  stands for a real-time node and  $n_{nrt}$  for a non-real time node. Therefore, the overall network made up of the two WSNs is denoted as  $\mathcal{N} = \{\mathcal{N}_{rt}\} \cup \{\mathcal{N}_{nrt}\}$ . Recall that RT nodes constitute of a network for sensing and routing RT messages whereas the NRT network senses and routes NRT messages. The objective of PADR is to make the two networks collaborate to ensure a prolonged life time for RT network. Fig. 2 illustrates our scenario where the two networks collaboratively forward the data to the sink.

We assume the two networks are deployed at the same time. At the beginning, the two networks under PADR operate without collaboration since each node has maximum power, Fig. 1. Since RT nodes consume power at a higher rate than NRT nodes, after some time of network's operation, RT nodes will have much less power remaining than NRT nodes. When the power of the next RT node reaches a critical value, the proposed PADR algorithm (Section V) choses a NRT node with maximum remaining power as the next forwarding node for RT traffic and continues to use the same forwarding node until its power also reaches critical value or until the network dies. PADR triggers similar swapping for NRT traffic.

For simplicity, PADR assumes that the power of same type nodes that are placed the same distance from the sink deplete at the same rate. Thus, if an RT next forwarding node has its power at critical value, all potential RT next forwarding nodes are at the same state. In case the next NRT node has

its power reaching a critical value, which must be lower than or the same as the critical value for RT nodes, a forwarding node under PADR selects the best RT node as the next hop, otherwise it selects a NRT node if no RT node is available. The critical power value for RT nodes in PADR can be set in such a way that the RT nodes will be able to forward some NRT data after swapping routing responsibility. Otherwise, swapping from NRT forwarding node to RT forwarding node as may be the case for NRT data routing won't be possible.

Therefore, PADR balances power consumption at the forwarding nodes by routing RT traffic through nodes with high residual power. This would extend the RT network life time by

- 1) Evading nodes that would quickly exhaust their power as a result of RT traffic being routed through them. Routing RT traffic without aggregation in order to meet their deadlines results in heavy traffic at the RT forwarding nodes which quickly exhaust their power. But when RT traffic is routed through the energy rich nodes, RT packet drop rates are minimized or even eliminated.
- 2) Secondly the number of NRT transmissions is reduced through NRT packet aggregation [6], thus power consumed at NRT node in transmitting NRT traffic is reduced throughout the network.

## III. SENSOR NODES' LIFE TIME

In this section, we derive expressions for life time of RT and NRT sensor networks with and without PADR. We define life time of a sensor network as the time from when the network was first switched on to the time when the network fails to operate. We assume that the failure of the network is only due to inability of some nodes in the network to forward data. We present numerical results that compare network life time of RT and NRT networks without PADR and with PADR.

### A. Node Life Time

The rate at which the power of a sensor node depletes varies with the distance of the node from the sink. Here we consider a concentric topology with the sink located at the center, The nodes are evenly distributed in such a manner that forwarding nodes at  $h$  hops from the sink have equal number of  $h+1$  hop nodes from which they receive data packets. Also, the number

of nodes that forward to one routing node is the same for all nodes at the same hop. Equations (1-2) are derived from [5]. We use them in this paper to derive the expressions for life time of a sensor node and life time of RT and NRT networks.

Let  $h$  be the number of hops from any sensor node to the sink,  $\alpha$  be the density of the sensor deployment, then the number of sensor nodes  $n$  existing in an area  $h$  hops away from the sink is given by:

$$n = [(hr)^2 - \{(h-1)r\}^2]\alpha \quad (1)$$

where  $r$  is the constant distance between successive hops as indicated in the topology diagram. Sensor nodes  $n$  act as forwarding nodes for those nodes which are  $h+1$  hops. The total number of sensor nodes  $n^T$  which depend on intermediate forwarding nodes  $n_f$  that are located at  $h$  hops from the intermediate forwarding nodes is given by:

$$n^T = [(mr)^2 - (hr)^2]\alpha \quad (2)$$

where  $m$  is the maximum number of hops in the sensor network. The total number of sensor nodes that one forwarding node located  $h$  hops from the sink has to support in terms of forwarding their data is obtained from Equations (1) and (2) as follows:

$$n_f^T = \frac{n^T}{n} = \frac{[(mr)^2 - (hr)^2]\alpha}{[(hr)^2 - \{(h-1)r\}^2]\alpha} = \frac{m^2 - h^2}{2h-1} \quad (3)$$

The rate at which each sensor node consumes its power depends on the amount of data it has to forward to the next hop, the same as the number of nodes it supports (Equation 3). We therefore obtain the expression for consumed power by a node  $i$ , ( $P_i$ ) as

$$P_i = P_{max} \left( \frac{\frac{m^2 - h^2}{2h-1}}{(mr)^2 \alpha} \right) \quad (4)$$

The smaller the maximum number of hops ( $m$ ) the higher the density of nodes, meaning there are more forwarding nodes within a given area of the network and therefore they are closer to each other. Being closer, the nodes share incoming traffic among themselves based on the ratio of their residual powers and thus no one node is overwhelmed by traffic. Thus each forwarding node routes fewer number of packets hence low power consumption. On the contrary, higher maximum number of hops means the nodes are sparsely placed, each forwards more number of data packets and hence higher power consumption at such a forwarding node.

Now, suppose each sensor node has a data generation rate of  $\beta$  data units (packets) per unit time  $t$ , then the number of data packets that any single sensing node generates in time  $t$  is  $\beta t$ . Thus, from Equation (3) the number of data packets that a forwarding node located at  $h$  hops from the sink would have to relay in time  $t$  is:

$$\left( \frac{m^2 - h^2}{2h-1} \right) \beta t \quad (5)$$

Since RT traffic requires urgent delivery to the sink, its data packets are forwarded immediately. If Mica2 is used, power

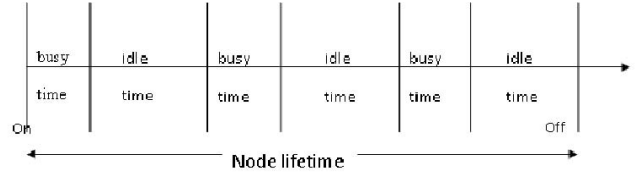


Fig. 3. Illustrating node's life time

consumed in receiving and transmitting  $\beta$  data packets are  $\frac{m^2 - h^2}{2h-1} 8\beta t$  and  $\frac{m^2 - h^2}{2h-1} 20\beta t$  respectively (See [1] for detailed specifications). Thus the total energy consumed by a node located  $h$  hops from the sink in time  $t$  when transmitting data at a rate of  $\beta$  is  $28 \left( \frac{m^2 - h^2}{2h-1} \right) \beta t$ . This is the minimum power any forwarding node at such a number of hop from the sink requires for successful communication of a single data unit. Therefore a forwarding node at  $h$  hops from the sink will forward  $R$  data packets at a rate  $\beta$  packets per unit time where  $R$  is given as:

$$\begin{aligned} R &= \frac{\text{Initial power} - \text{minimum threshold power}}{\text{minimum threshold power}} \\ &= \frac{P_{max} - \frac{28(m^2 - h^2)}{2h-1} \beta t}{\frac{28(m^2 - h^2)}{2h-1} \beta t} \\ &= \frac{(2h-1)P_{max}}{28(m^2 - h^2)\beta t} - 1 \end{aligned} \quad (6)$$

where  $\tau$  is the total busy time a node is receiving and sending a data packet. Node's life time ( $T$ ) is therefore given as:

$$T = R\tau = \left[ \frac{(2h-1)P_{max}}{28(m^2 - h^2)\beta t} - 1 \right] \tau \quad (7)$$

Equation (7) is valid when the node is constantly busy  $\tau$  unit times ( $\tau = \frac{1}{\beta}$ ). Thus  $\tau$  is high for NRT and low for RT due to the high data transmission rate for RT network and low data transmission rate for NRT network respectively. We extend the expression in Equation (7) to include scenarios when the network is sometimes idle and sometimes busy as illustrated in Figure 3.

Let's denote busy and idle times as  $t_{rt,b}, t_{nrt,b}$  and  $t_{rt,i}, t_{nrt,i}$  for RT and NRT nodes. Let also that the mean busy time for RT and NRT nodes be denoted by  $\overline{t_{rt,b}}$  and  $\overline{t_{nrt,b}}$  respectively, and the idle times for RT and NRT be denoted as  $\overline{t_{rt,i}}$  and  $\overline{t_{nrt,i}}$  respectively. Therefore, the time between data transmissions for RT traffic is given as  $\tau_{rt} = \overline{t_{rt,b}} + \overline{t_{rt,i}}$  and the time between data transmissions for NRT traffic,  $\tau_{nrt} = \overline{t_{nrt,b}} + \overline{t_{nrt,i}}$ . The nodes life time for a node type  $k$  is therefore obtained as:

$$\begin{aligned} T_k &= \left[ \frac{(2h-1)P_{max}}{28(m^2 - h^2)\beta t} - 1 \right] \tau_k \\ &= \left[ \frac{(2h-1)P_{max}}{28(m^2 - h^2)\beta t} - 1 \right] (\overline{t_{k,b}} + \overline{t_{k,i}}) \end{aligned} \quad (8)$$

where  $k \in \{rt, nrt\}$ .

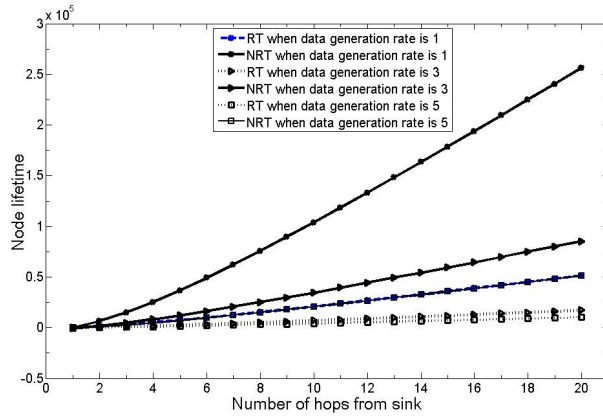


Fig. 4. RT and NRT nodes life time at different data generation rates

NRT sensors are often triggered by some changes in physical phenomena being studied. Thus the distributions of idle and busy times aren't easy to determine whereas busy and idle times for RT sensors should be periodic in nature with longer busy times than idle.

We next use three different data generation rates  $\beta = 1, 2, 3$  packets per unit time to compare node's life time for both RT and NRT traffic. The results are shown in Fig.4. The figure shows that life time of RT and NRT nodes at different hops away from the sink for for a WSN with 100 nodes. It is easy to see that the life time of RT nodes is shorter than that for NRT at the same data generation rate. RT network forwards its data packets more frequently than the NRT network, hence dissipating more energy than the NRT forwarding nodes. This means its energy reserve would be exhausted within a shorter time than that of NRT nodes.

Nodes on low data generation rate forward fewer number of data packets than those that are on high data generation paths, and therefore have their power consumed at lower rate. These nodes have longer life than those that receive and forward regularly. At the same deployment density, nodes closer to the sink have their life times close to each other since these nodes forward almost the same number of data packets, given the closeness in the data generation rates. But further away from the sink, nodes along paths with higher data generation rate have much shorter life time than those on paths forwarding data generated at the rate of 1 data packet per unit time.

#### IV. NETWORK LIFE TIME UNDER PADR

Network life time (**Netlife time**) is the time it takes from the when the network is switched on until it cannot transmit data to the sink due to nodes failures due to lack of power. Assuming that the power of nodes that are at the same distance from the sink dissipates power at the same rate, then Netlife time is equivalent to node's life time at a given distance from the sink. In this section we derive Netlife time of RT and NRT networks under PADR algorithm. Recall that PADR assumes that a node is capable of transmitting both RT and NRT traffic. Therefore, the definition of Netlife time for RT network under PADR is

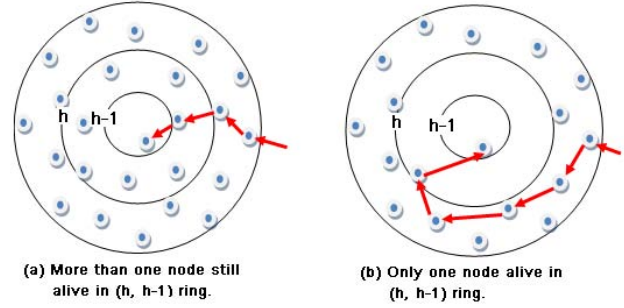


Fig. 5. A single node within a ring sustaining network life time

the time it takes until nodes are incapable of transmitting RT traffic to the sink, similarly for Netlife time for NRT network.

In a wireless sensor network deployment of  $n$  forwarding nodes all within a  $(h, h - 1)$  ring, let  $T$  be the life time of a node. We assume that in any ring, communication may continue as long as there exists at least one node within the ring that still has sufficient power to forward data packets. But once all nodes fail a transmission gap is created and thus a disconnected network. Fig. 5 represents a scenario where routing path creation may still be possible in the presence of a single forwarding node within the ring, otherwise the network is considered dead.

When all forwarding nodes at a given distance from the sink fail the network is completely disconnected resulting into total communication failure, this is when network is confirmed to have reached its Netlife time. Since we all assume nodes in a ring have the same remaining power, then Netlife time of a network is equivalent to the longest life time of the node in the closest ring to the sink.

##### A. PADR Netlife time

In this section we show the disparity in Netlife time of RT and NRT Networks, improvement that PADR introduces to RT traffic routing environment, and the degradation in Netlife time that PADR brings to NRT traffic routing environment, all as a function of parameters that define points for PADR to swap forwarding capabilities between nodes types. Fig. 6 shows how faster a RT network dies than a NRT network, thus use of NRT nodes as backup nodes for RT traffic routing is necessary in order for the two networks do die smoothly over time.

RT network can have very short Netlife time as compared to NRT Network, yet RT traffic is more critical and needs to be relayed to the sink quickly with no (or little) loss. This fast death of a RT network is therefore unacceptable, thats why we introduce idea of super-imposing the two networks so that they collaborate to help prolong RT Netlife time. PADR reaps the benefit of routing its RT traffic through RT network and when the power level of RT network drops below acceptable threshold it routes RT traffic through energy rich NRT forwarding nodes.

Let  $T_{rt}$  and  $T_{nrt}$  denote node life time of RT and NRT nodes respectively. Node life time of RT node that forwards

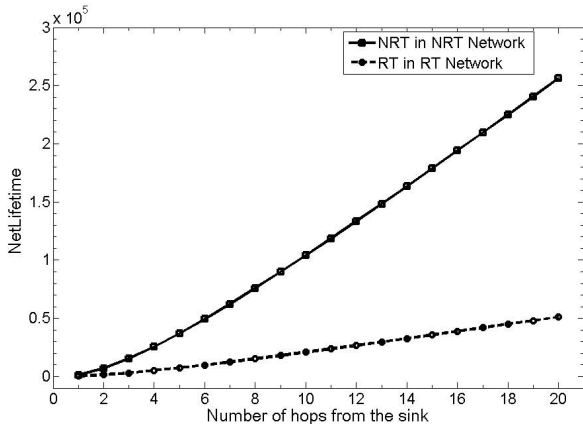


Fig. 6. Netlife time of RT and NRT networks

RT data for  $\gamma$  fraction of time and NRT data for  $(1 - \gamma)$  fraction of time is given as:  $\gamma T_{rt} + (1 - \gamma)T_{nrt}$ . Similarly, node life time of NRT node that serves NRT traffic only for  $\mu$  unit of time and both RT and NRT traffic for  $(1 - \mu)$  fraction of time is given as:  $\frac{(1 - \mu)(T_{rt} + T_{nrt})}{2} + \mu T_{nrt}$ . NRT nodes provide backup support to power-critical RT nodes for  $(1 - \mu)$  fraction of NRT node's life time. These two relationships represent the fraction of time a node routes either RT or NRT traffic before negotiating a balance between RT forwarding responsibility and NRT forwarding responsibility.

Note that the life time under PADR involves the transmission time of traffic through both RT and NRT nodes due to swapping routing responsibilities. Therefore, the life time of nodes due to RT traffic transmission under PADR is obtained by combining all components with  $T_{rt}$  as:

$$T_{rt}(PADR) = \frac{(2\gamma - \mu + 1)}{2} T_{rt}, \quad (9)$$

and the life time of nodes due to transmission of NRT traffic routing under PADR is

$$T_{nrt}(PADR) = \frac{(\mu - 2\gamma + 3)}{2} T_{nrt} \quad (10)$$

Then the ratio of Netlife time between a network with PADR protocol and a network without PADR obtained as:

$$Ratio_{rt} = \frac{2\gamma - \mu + 1}{2}, \quad (11)$$

and

$$Ratio_{nrt} = \frac{\mu - 2\gamma + 3}{2} \quad (12)$$

Realistically, PADR should swap forwarding task from RT to NRT when RT has consumed a large fraction of its energy (i.e., for large  $\gamma$  values). We next look for the values of  $\mu$  under which PADR will offer the highest benefits in terms on improving the Netlife time of RT network under PADR. Table I and Table II show the ratios of RT and NRT for values of  $\gamma = \{0.7, 0.8, 0.9, 1\}$  and for values of  $\mu = \{0.1, 0.2, \dots, 1\}$ . Since PADR is triggered by RT nodes to change the forwarding node, the values of  $\mu$  in the tables can be interpreted as the

| $\mu$ | $\gamma=0.7$ | $\gamma=0.8$ | $\gamma=0.9$ | $\gamma=1.0$ |
|-------|--------------|--------------|--------------|--------------|
| 0.1   | 1.1500       | 1.2500       | 1.3500       | 1.4500       |
| 0.2   | 1.1000       | 1.2000       | 1.3000       | 1.4000       |
| 0.3   | 1.0500       | 1.1500       | 1.2500       | 1.3500       |
| 0.4   | 1.0000       | 1.1000       | 1.2000       | 1.3000       |
| 0.5   | 0.9500       | 1.0500       | 1.1500       | 1.2500       |
| 0.6   | 0.9000       | 1.0000       | 1.1000       | 1.2000       |
| 0.7   | 0.8500       | 0.9500       | 1.0500       | 1.1500       |
| 0.8   | 0.8000       | 0.9000       | 1.0000       | 1.1000       |
| 0.9   | 0.7500       | 0.8500       | 0.9500       | 1.0500       |
| 1.0   | 0.7000       | 0.8000       | 0.9000       | 1.0000       |

TABLE I  
RATIO OF RT NETLIFE TIME AS A FUNCTION OF  $\gamma$  AND  $\mu$

| $\mu$ | $\gamma=0.7$ | $\gamma=0.8$ | $\gamma=0.9$ | $\gamma=1.0$ |
|-------|--------------|--------------|--------------|--------------|
| 0.1   | 0.8500       | 0.7500       | 0.6500       | 0.5500       |
| 0.2   | 0.9000       | 0.8000       | 0.7000       | 0.6000       |
| 0.3   | 0.9500       | 0.8500       | 0.7500       | 0.6500       |
| 0.4   | 1.0000       | 0.9000       | 0.8000       | 0.7000       |
| 0.5   | 1.0500       | 0.9500       | 0.8500       | 0.7500       |
| 0.6   | 1.1000       | 1.0000       | 0.9000       | 0.8000       |
| 0.7   | 1.1500       | 1.0500       | 0.9500       | 0.8500       |
| 0.8   | 1.2000       | 1.1000       | 1.0000       | 0.9000       |
| 0.9   | 1.2500       | 1.1500       | 1.0500       | 0.9500       |
| 1.0   | 1.3000       | 1.2000       | 1.1000       | 1.0000       |

TABLE II  
RATIO OF NRT NETLIFE TIME AS A FUNCTION OF  $\gamma$  AND  $\mu$

values of  $\mu$  when the corresponding NRT node is selected as the next forwarding node for RT traffic.

Perhaps rather expectedly, Table I shows that the Netlife time for RT traffic under PADR increases as the values of  $\gamma$  increase, and that RT transmission under PADR exhibit high Netlife time for small values of  $\mu$ . Large values of  $\mu$  mean that little energy is left when NRT node is chosen to forward RT traffic. In this case, the table shows a decrease in the ratio and thus the Netlife time for RT network. This means that PADR doesn't improve RT Netlife time under large  $\mu$  values.

Preferably, the best values of  $\gamma$  and  $\mu$  should provide as small Netlife time degradation for NRT network as possible under PADR. Table II shows the ratio of Netlife time under PADR and without PADR as a function of  $\mu$  and  $\gamma$  values. We observe that NRT Netlife time is longer at small  $\gamma$  values, and seems to increase with increasing  $\mu$  values.

Numerical results in this section show that reaping the benefits of PADR highly depends on the amount of remaining power both RT and NRT nodes when swapping of forwarding capabilities is executed. It is however a very daunting task to obtain the best swapping points (i.e., values of  $\mu$  and  $\gamma$ ) because energy consumption between the two types of networks is independent. It may be possible to set sensing rates of RT and NRT for very special cases of applications in such a way that swapping of nodes coincide with the best  $\mu$  and  $\gamma$  values. But this is beyond the scope of this paper.

Consider the results for a special case when all the energy of RT nodes is used to forward RT traffic, i.e  $\gamma = 1.0$  and a small value of  $\mu = 0.1$ . Given that RT nodes deplete their

power much faster, this can be one of the best case realistic scenario. The tables show that for these parameters the netlife time of RT network under PADR is reduced by 45% whereas the netlife time of NRT network is increased by around 55%.

## V. PADR ALGORITHM

In this section we present an overview of PADR algorithm and a pseudocode for swapping routing responsibility between RT and NRT nodes. Initially, we assume all nodes (both RT and NRT) have the same power level and each traffic type (RT traffic and NRT traffic) is being routed by its' own network as depicted in Fig. 1. RT forwarding nodes will have their power depleted at a higher rate than NRT nodes. Therefore, after sometime the remaining power of RT nodes will reach a critical value prompting the routing algorithm to swap the routing responsibility of RT traffic from RT nodes to NRT nodes. PADR allows identification of next appropriate forwarding node for NRT traffic in a similar fashion. Depending on the value of remaining power in RT nodes when forwarding responsibility is swapped, swapping NRT forwarding nodes from NRT to RT may be rare or nonexistent.

PADR algorithm has two components: 1) Real-Time Forwarding algorithm component which ensures that RT packets are forwarded through available capable RT or NRT nodes, thus minimizing RT data drop rate and even ensuring that it travels faster than NRT data, 2) Non-Real Time Forwarding algorithm component on the other hand manages the forwarding of non-real time traffic through either RT or NRT nodes. Next we show the pseudocode of PADR algorithm that considers swapping on only nodes that forward RT data.

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1: if node  $j \in \text{RT}$  then
2:   Find the next hop RT node for RT traffic forwarding
3:   Compute  $w_{rt,j}$  for each neighboring node along the
   path
4:   for ( $w_{rt,j} \geq w_{min}$  and  $n_{rt,j}$  maximum) do
5:     Add  $n_{rt,j}$  to a list corresponding to forwarding nodes
     on a route
6:   end for
7:   for ( $w_{rt,j} \leq w_{min}$ ) do
8:     Use node  $n_{rt,j}$  to forward NRT traffic only
9:     Find NRT nodes  $n_{nrt,j}$  with  $w_{nrt,j} \geq w_{min}$ 
10:    Add next hop NRT node  $n_{nrt,j}$  with highest weight
    to RT traffic routing path
11:  end for
12: else
13:   Drop the packet
14: end if

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$w_{rt,j}$  is weight function, in terms of remaining power in the nose of a neighboring nodes of node  $j$ , and  $w_{min}$  is the minimum power value required to forward RT data. Implementation of PADR requires that forwarding nodes periodically exchange information on their residual power and location. This can be achieved through BEACON messages exchanged amongst neighbor nodes every  $t_{beac}$  interval of time. PADR uses the information in the BEACON message to compute nodes weights. Detailed implementation and evaluation of

PADR algorithm, including computation of weights, is considered for future work.

## VI. CONCLUSION

We considered a sensor field where two heterogeneous wireless sensor networks; for real-time (RT) and non-real time (NRT) applications, are deployed. These types of applications are known to have different network requirements and thus impose different demands to sensing devices. In particular, RT sensor nodes often sense and forward data periodically at higher rates than NRT nodes, leading to a higher rate of power consumption. As a result, sensor nodes RT WSNs see their power dissipated much faster than nodes in NRT networks leading to shorter life time to real-time networks.

In this paper, we proposed a power-aware routing algorithm called *power-aware differentiated routing* (PADR) algorithm to enable heterogeneous wireless sensor networks to collaborate in order to prolong transmission of real-time traffic. This being a preliminary work, we investigated PADR algorithm analytically and derived expressions for node life time and network life time, i.e, the time it takes until a network fails to deliver data to the sink (*Netlife time*). The numerical results show that PADR can be used to increase Netlife time of RT network by up to 50%. The results also show that the increase in Netlife time for RT network comes *at the* expense of reducing the Netlife time of NRT network. However, given that NRT network without PADR exhibit significantly much longer Netlife time, the reduced Netlife time of NRT network under PADR can still be longer than or equal to the improved Netlife time of RT network under PADR.

We plan to use simulations in future to show how PADR performs under different traffic conditions, the QoS guarantees that come with PADR, node life time and consequently Network life time duration under PADR as compared to other WSN routing protocols.

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