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An Energy Efficient Opportunistic Routing Metric for Wireless Sensor Networks

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Abstract

Objectives: Opportunistic Routing (OR) algorithms depends on metric design applied to the forwarder selection and prioritization. The objective is to define new OR metric, which reduces energy consumption in WSN. **Methods/Statistical Analysis**: In Wireless Sensor Network (WSN), sensor nodes have been supplied with a small amount of energy, using small size battery. Opportunistic Routing (OR) can minimize energy consumption by reducing delay and providing real time data delivery. OR reduces number of retransmissions in network by increasing the number of tentative forwarders. But most of the OR algorithms depends on metric design applied to the forwarder candidate selection and prioritization. **Findings**: In this paper, a new energy aware opportunistic routing metric called as Energy Depletion Factor (EDF) is proposed for WSN. This metric takes into consideration energy as well as delay. This metric can directly be used with existing opportunistic routing protocols. This metric extends the lifetime of the network by distributing energy consumption load equally in the network. It tells the routing algorithm that which forwarder node is having what impact on its battery life. EDF is local opportunistic routing metric, which reduces end-to-end delay in the network and also increases the network lifetime. To calculate EDF, the concept of residual energy of each node has been used. **Application/Improvements**: This metric can directly be used with existing opportunistic routing protocols. Simulation results presented the improvement of network lifetime and throughput by using EDF as a routing metric in WSN.

Keywords: Energy Depletion Factor, End-To-End Delay, Energy Efficiency, Network Lifetime, Opportunistic Routing Metric, Routing Algorithm

1. Introduction

Wireless sensor network is an emerging technology with a rapid increase in number of applications. Due to recent technical advancements in WSN, it is now feasible for sensor nodes not only to gather non-real time data but also to collect data in more problematical real-life applications. WSN has been prolonged to take account of actuator nodes with sensor nodes and some researchers call it as sensor and actuator networks[1].

As all the actuators and sensor nodes are energy constrained, the WSN researchers from different parts of world are trying to diminish the energy consumption and increasing the network lifetime of network. In real life applications of WSN, lifetime should be increased without risking the real time communication from node to node or to base station (sink). Taking the example of surveillance system the data should be reported to base station within a few seconds of exposure. Unluckily, there are only few researches in the world which are working on real time communication in WSN.

There is a lot of research work that focuses upon the communication techniques because radio communication unit consumes most of the energy of sensor node. The receiver and transmit electronics consume almost about one thousand CPU units[2].

To reduce or optimize the energy consumption, lot of energy aware metrics was proposed in the literature. However, most of these ignore the real time aspect of the real-time requirements. In[3] Proposed a real time power aware routing algorithm (RPAR, which decreases the communication delays in view of transmission power,

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in the workload of the network. The algorithm do not optimize the network lifetime. In[2] Proposed a routing algorithm which works in a real time scenario and try to reduce the network lifetime. But, in this algorithm the link reliability has not been considered and hence the algorithm's reliability also decreases. In WSN, a routing algorithm that does not consider the reliability of the link may suffer from high delays in delivering the packets and there will be increased number of retransmissions. This will increase the energy consumption.

To tackle with these problems[4] designed a new protocol using Expected Transmission Count (ETX)[5] as a metric and named it as ExOR (Exclusive Opportunistic Routing). This method is not mainly for WSN, because it do not consider the energy efficiency as its' primary objective. The idea was to reduce number of retransmissions of data packets. ETX was directly affects the throughput because it is based on the delivery ratios of wireless links.

In this paper the conception is to present a new opportunistic routing metric which can optimize between power consumption and delay in WSN. This paper tries to find out a new metric which can consider the requirements of real time communications, i.e. delay, energy and link reliability.

The rest of this research paper is organized as follows. In section 2, outline of related work will be given. Section 3 provides proposed routing metric and its mathematical analysis. Experimental analysis has been given in section 4. Simulations will compare the performance of proposed metric approach with the existing ones in this section. Finally, section 5 gives the conclusions.

2. Related Work

The most popular table-driven routing algorithms Ad-hoc on-demand Distance Vector (AODV) and Destination-Sequenced Distance Vector routing (DSDV), use smallest hop counting as a metric to decide the next forwarder node. AODV is also source initiated protocol[6]. Source initiated, here means that route will be decided only when there is a requirement by the source node. The routes have been maintained by the routing table as long as the source requires these routes. AODV neglects the energy issue and is not suitable for WSN.

For WSN several routing protocols has been proposed for example[7-9]. In[9] Presents an energy metric which is optimally bounded and tries to increase the network lifetime [8] have presented two energy efficient data forwarding schemes for single link and multiple links. Authors are able to reduce the energy consumption through this metric and able to find a trade-off between energy and delivery rate. These schemes has been enhanced later in[7], which considers the nodes' remaining energy into the forwarding metric. However, in all of these researches the consideration of delay in real-time applications is missing and there will be wastage of properties of broadcasting in wireless sensor networks.

Opportunistic routing metrics introduce the concept of reducing the number of retransmissions to save energy and taking the advantages of broadcasting nature of wireless networks. Broadcasting helps to discover as many paths in the network as possible. The transmission will takes place on any of these paths. If a path fails, the transmission can be completed by using some another path using other forwarder having the same packet.

As discussed earlier ETX was the first metric proposed for opportunistic routing in wireless networks. Working in the same direction many researchers have proposed new routing metrics such as EAX (Expected Any-path transmission)[10], mETX (modified ETX)[11], ENT (Effective Number of Transmissions)[11], ETT (Expected Transmission Time)[12], EDR (Expected Data Rate)[13], the EOT (Expected One hope Throughput)[14], OEC (Opportunistic End-to-end Cost)[15], and Opportunistic Expected One hope Throughput (OEOT)[16] and designed algorithms based on these. The last two metrics illustrate the trade-off between the advancement of packets and the packet forwarding time by incorporating routing aspects related to advancements of packets, forwarding delay, and link reliability.

The computation of opportunistic routing metrics mentioned above can be divided into two classes (global or local) reliant on the routing facts collection model (whether local or global). A global cost metric has been, typically, preserved by source node in the network[4, 10, 17-21] whether the local computation has been maintained in distributive manner[14, 22, 23]. A very low overhead has been introduced in calculating local metrics, while global metrics may lead to high computation overhead because of acquiring whole network knowledge. [24]Presented a different opportunistic routing approach and routing metric which is based on the transmission power control while transmitting a packet. The energy cost will be dependent on the number of transmissions made to a particular forwarder. But, the overhead of changing transmission power every time and maintaining the record of each node will be high. The proposed routing metric is also local in nature and perform distributive computations.

3. Proposed Routing Metric

Most of the researches discussed in related work above focuses transmission on unreliable links. In this paper new opportunistic energy efficient routing metric has been proposed, which extends the lifetime of the network by distributing energy consumption equally in the network. Lifetime here can be referred to as the percentile of nodes alive in the network after each round of routing. Basic energy cost model and the proposed metric has been given in the following subsections.

3.1 Energy Cost Model

In a wireless sensor network the sensor nodes have been supplied with a small amount of energy, depending on the application, using small size battery. Sensor nodes in WSN necessitate energy for sensing, processing, receiving and transmitting packets. The equations below given in[25], are the first order equalities for energy indulgence. A sensor node will take E_{Trans} energy when it wants to transmit n bit packet over distance l, it will be given by equation (1) below:

$$E_{Trans}(n,l) = \begin{cases} n.E_{R\_elect} + n.E_{R\_fs}.l^2, \; if\ l < l_0 \\ n.E_{R\_elect} + n.E_{R\_amp}.l^4, \; if\ l \geq l_0 \end{cases} \quad . (1)$$

When a sensor node receives n bit packet, it will ingest $E_{Recieve}$ amount energy given by equation (2) below:

$$E_{\mathrm{Receive}}(n) = n.E_{R\_elect} \ldots\ldots\ldots\ldots\ldots \quad .. (2)$$

Whenever a forwarder candidate node have to send n-bit data packet toward the base station, it's transmit electronic circuit consumes, $E_{Forward}$ energy.

$$E_{Forward}(n,l) = E_{Trans}(n,l) + E_{\mathrm{Receive}}(n)$$
$$= \begin{cases} 2n.E_{R\_elect} + n.E_{R\_fs}.l^2, \; if\ l < l_0 \\ 2n.E_{R\_elect} + n.E_{R\_amp}.l^4, \; if\ l \geq l_0 \end{cases} \quad .. \quad (3)$$

The description of parameters for sensor nodes is given in table 1.

3.2 Energy Metric

The metric proposed in this paper is named as Energy Depletion Factor (EDF), because this metric tells the routing algorithm that which forwarder node is having what impact on its battery life. As said earlier by[15] the transmission and reception energy for a packet may always be same for all nodes in the network but the impact of this energy consumption on life or residual energy of each node and also life of network will not always be same. For example, suppose that the residual energy of two nodes N_1 and N_2 is 6 units and 3 units, respectively. Also the distance of the next hope from N_1 is greater than that of N_2. Now a single unit of energy consumption cost 50% of residual energy of N_1 and for N_2 it is 20%. In this scenario the node N_1 will die only after two transmissions. So in order to identify these types of impacts on the lifetime of the network EDF is aimed. Similar work has been done by[15], but the metric proposed by them was fall in the category of global opportunistic metrics and the end-to-end delay in this case is high. EDF is local opportunistic routing metric, which reduces end-to-end delay in the network and also increases the network lifetime.

Table 1. Wireless parameters description

Parameter	Definition	Value/Unit
E_{R_elect}	Energy dissipation to run the radio	50 nJ/bit
E_{R_fs}	Free space model of transmitter amplifier	10 pJ/bit/m^2
E_{R_amp}	Multi-path model of transmitter amplifier	0.0013 pJ/bit/m^4
n	Data length	2,000 bits
l_0	Distance threshold	$\sqrt{\frac{E_{R\_fs}}{E_{R\_amp}} n}$

To calculate EDF, the concept of residual energy of each node has been used. Firstly, the scariness (SEC_{Ni}) on residual energy (RE_{Ni}) of a sensor node N_i has been calculated over energy consumption (EC), as follows:

$$SEC_{N_i} = \frac{EC}{RE_{N_i}} \ldots\ldots \qquad \ldots\ldots\ldots\ldots (5)$$

SEC_{Ni} prevent the depletion of the whole energy of a node. Taking the example given earlier suppose some source node broadcast the packet to N_1 and N_2 (Neighbors of S). After receiving the packet the SEC_{Ni} for transmission is computed. According to the above example SEC_{Ni} cost of transmission for both N_1 and N_2 comes out to be 0.3008 and 0.88 respectively. Now as the distance of node N_1 is greater, but SEC_{N1} is less than that of N_2, it will become the forwarder, and forward the packet first. If we choose N_2 as a forwarder because of less distance it will drains out of its energy soon, decreasing the network lifetime immediately as a result. This is the case of only transmission energy consumption. To compute SEC_{Ni} for all energy consumption in a node and the network EDF has been formulated. EDF metric contains the following components: 1) SEC_{Ni} cost from node to its forwarders, 2) SEC_{Ni} cost of receiving data, 3) the estimated SEC_{Ni} cost of retransmission, and 4) SEC_{Ni} cost of acknowledgement. The EDF for node N_i is computed hop-by-hop opportunistically by the following equation:

$$EDF_{Ni} = \frac{E_{tx:Ni->fwd} + E_{rx:Ni} + E_{re\_tx:Ni->fwd} + E_{ACK:Ni->source}}{RE_{Ni}} .. \tag{6}$$

Each term in this equation can be given in detail as below.

a) $E_{tx:Ni->fwd}$ is the SEC cost of the node N_i used in broadcasting the *k*-bit data packet from N_i to its' forwarders using transmission power E_{Trans} (equation (1)) and is given by the following formula:

$$E_{tx:Ni->fwd} = \frac{E_{Trans}}{RE_{Ni}} \ldots\ldots\ldots \qquad \ldots\ldots. \tag{7}$$

b) $E_{rx:Ni}$ is the SEC cost of the node Ni used in receiving a k-bit data packet from source or other nodes receiving power $E_{Receive}$ (equation (2)) and is given by the following formula:

$$E_{rx:Ni} = \frac{E_{\text{Receive}}}{RE_{Ni}} \ldots\ldots\ldots\ldots\ldots.. \tag{8}$$

c) $E_{re\_tx:Ni->fwd}$ is the SEC cost of retransmitting a packet to its' forwarders using transmission power E_{Trans} and receiving power $E_{Receive}$. This transmission and receiving cost has been combined into a single energy cost denoted as $E_{Forward}$ (equation (3)). This cost is given by the following formula:

$$E_{re\_tx:Ni->fwd} = \frac{E_{Forward}}{RE_{Ni}} \ldots\ldots\ldots\ldots\ldots.. \tag{9}$$

d) $E_{ACK:Ni->source}$ is the SEC cost of the node Ni in broadcasting the k-bit acknowledgement packet from Ni using transmission power E_{Trans} (equation (1)) and is given by the following formula:

$$E_{ACK:Ni->source} = \frac{E_{Trans}}{RE_{Ni}} \ldots\ldots\ldots\ldots\ldots.. \tag{10}$$

After the calculation of all these values, EDF for node Ni is computed using equation (6). Similar process will be followed by other forwarder nodes in the forwarder list of source node. The forwarder with the minimum value of EDF will be the candidate who forwards the data packet first and rest of all nodes in forwarder list will wait for acknowledgement from this node. EDF will do energy consumption distribution, as there is not always a single node transmitting data again and again. The forwarder is selected on the go opportunistically.

4. Experimental Results and Performance Analysis

The following norms are considered in this research paper.

a) Research considers that WSN contains a base station/sink and erratically dispersed static sensor nodes.

b) Nodes produce data arbitrarily to transmit to base station.

c) End-to-end delay has been considered as the time elapsed between initialization of communication from source node and reception of first packet at the base station.

4.1 Performance Analysis

The performance of proposed metric has been tested by performing simulations in MATLAB. Here, single base station application has been considered with static sensor nodes in a specified field. The transmission has been considered successful only when base station receives the packet. We have done many experiments considering the single base station only. The data source has been chosen randomly form N sensor nodes. The source chosen start transmitting the data towards base station by using multiple hops. The simulation will terminate the sensors having energy lower than 0.2 joules.

AODV routing is used as routing protocol in this paper. AODV has been modified to use proposed metric, minimum energy and minimum distance as next hop selection parameters. After this, we have compared the performances of all three types in terms of following performance parameters: 1) Network Lifetime, which is defined as a percentage of energy available in the network and it depends on the number of dead nodes after each simulation rounds, 2) Throughput, which is defined as the average number of packets received at base station per round, 3) Path Loss, which is the loss of packets or bits during the transmission of packets, due to the transmission channel, 4) End-to-End Delay, which is the average time of transmitting data form source to sink per round.

Figure 1 show that the network lifetime in first few rounds is 100 percent because no node is dead by that time. But after some time nodes start decaying, and the network lifetime goes on decreasing until whole of the network stops functioning. The figure shows that the proposed metric presents better lifetime preservation than the other two metrics. From this we can depict the good performance of opportunistic routing metric. EDF selects best forwarder among all of the neighbors of source node. In figure 2, the throughput of the network can be seen. Throughput of the network is the biggest factor of network performance. Proposed opportunistic routing metric (EDF) has shown a far better throughput than the other schemes. The throughput depends on many factors, but in this case we have considered the number of packets received at base station per round. The number of packets transmitted and received depends on the lifetime of the network and also delay introduces in transferring the packets from source to base station.

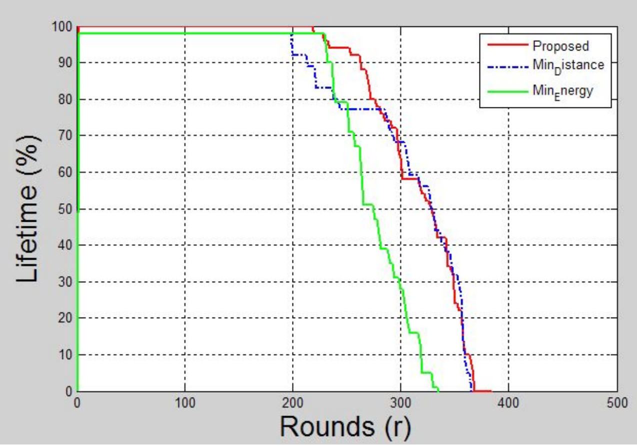

Figure 1. Network Lifetime.

Figure 3 shows the path loss incurred during the transmission of packets in each round of routing. Path loss is also a major factor, because number of successful packets received at base station depends on the path loss. If path loss is high, as in case of minimum energy and minimum distance metrics, than number of packets dropped increases and throughput decreases. Also the number of retransmissions increases due to increase in path loss. Figure 4 gives the end-to-end delay, which shows the performance of the network in terms of reliable and efficient delivery of the packets. Again EDF shows good performance and reduces end-to-end delay during transmissions.

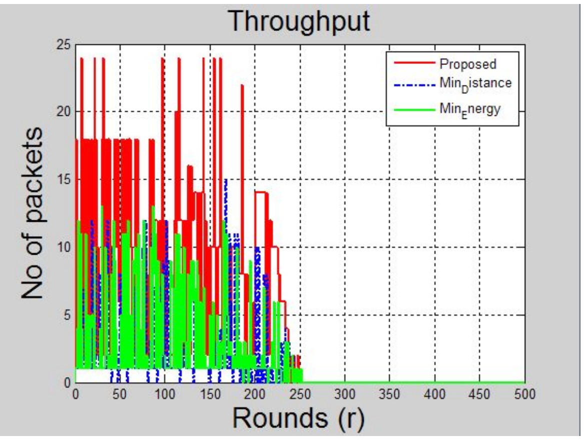

Figure 2. Throughput.

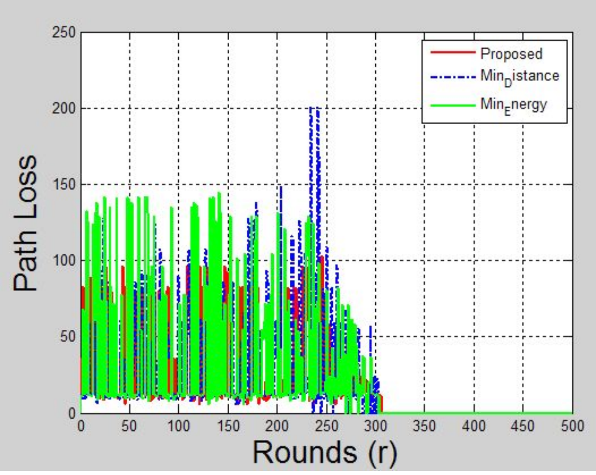

Figure 3. Path Loss.

5. Conclusion

In this paper, we have proposed an opportunistic routing metric called as EDF (Energy Depletion Factor). This metric is a distributed routing metric. The metric exploit the advantages of broadcasting in opportunistic routing and decide the next hop centered on the energy depletion of sensor nodes. The metric mutually contemplates the energy cost of transmission and residual energy of each sensor and the transmission reliability through a particular neighbor. The routing metric can be efficiently computed at any node with a less overhead. The routing has been conducted by using AODV mechanism and selecting forwarders on the basis of proposed metric. Simulation results show that EDF increases the network lifetime, throughput by reducing the path loss and end-to-end delays.

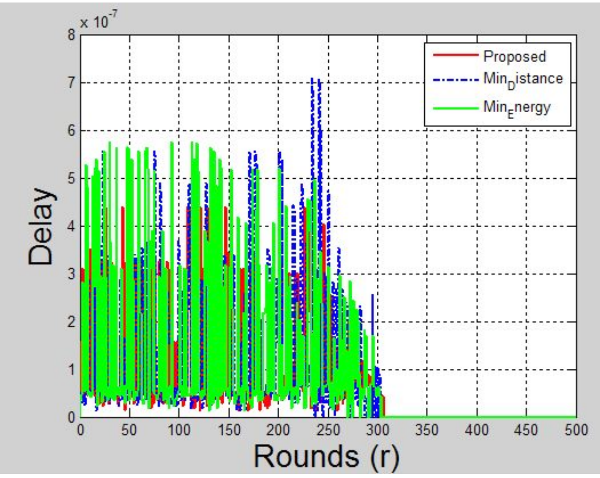

Figure 4. End-to-End Delay.

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