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A Mutlipath Routing Algorithm for Wireless Sensor Networks Under Distance and Energy Consumption Constraints for Reliable Data Transmission

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Abstract: Many applications of wireless sensor networks are critical such as, medical, crisis management, environmental, military, transportation, emergency, security applications. These applications require reliable data collection and achievement. Researchers have been investigated in this area proposing many techniques for WSN reliability meet, such as redundancy or retransmission mechanisms or multipaths routing protocols, some of these techniques dont care about the WSN limitation resources such as energy consumption. In this paper we propose a multipath routing algorithm for WSN for reliability data transmission, considering distance and energy consumption constraints.

Keywords: Wireless Sensor Network, Multipath Routing Algorithm, WSN Energy Consumption, Distance and RSSI, Wireless Sensor Network Reliability

1. Introduction and Overview

Wireless sensor networks (WSNs) are composed of low cost and resources components, they are used in many applications [12] (medical, crisis management, environmental, military, transportation, security, emergency) to sense and transmit the sensed data. Some of these applications are critical and the data require high level reliability transmission. In general, reliability is the probability that the system operates successfully for a given period of time under environmental conditions [2], [3]. This definition of system reliability is quantified by a probability of success, the environmental conditions may include not only temperature, atmosphere, and weather, but also load or traffic [2]. The successful operation can be interpreted as how many nodes can communicate with each other (sink to destination or all nodes). The focus on communication between tow nodes, assumes that there is a number of operating links and nodes that can connect the sink node to the destination one. In wireless sensor networks (WSNs) this kind of communication is said endto-end communication. The two nodes communication can be extended to all nodes communication and is called hop-byhop communication. In a wireless sensor network reliability can be defined as the ability of a network to carry out a desired operation such as communication [1]. The desired operation in this case is to ensure energy efficient and reliable transport of data [4] between two nodes and/or all nodes in the network.

The reliability is assured by retransmitting of loss packets or by redundancy mechanisms. The retransmission consist on retransmitting the lost packets [4] and the redundancy mechanisms uses a form of coding schemes [5]. The two mechanisms can be used in the hop-by-hop and end-to-end networks. In the one hand hop-by-hop, intermediate nodes allows to perform retransmission or redundancy, in the other hand retransmission and redundancy are performed in the source and destination nodes [4]. Another category to ensure reliability is event reliability, which is based on the amount of data to be delivered to node about the occurrence of an event in the environment. The last technique used to ensure reliability in WSNs is the multipath routing techniques. Several researchers proposed many multipath routing techniques, with or without energy consumption constraint. In [6] the authors have focused on the trade-off optimization problem to achieve energy efficiency in ad hoc network systems. The trade-off optimization is done between the improved spatial balance of energy burdens and the energy cost of spreading traffic. The authors in [7] have proposed a secure and energy efficient multipath routing protocol by formulating the secretsharing-based multipath routing problem as an optimization problem. The main objective of the optimization problem is to maximize the network security and lifetime, subject to the energy constraints. Authors in [8] have proposed a multipath ring routing protocol, that separate nodes in sections using ring level to increase the reliability data transmission. In [9] authors tested and simulated a multipath rings protocol implemented in Castalia [10] and Omnett++[11] simulator. The proposed protocol is based on a technique called Synopsis diffusion to determine the rings. They have compared the obtained results with a single path routing protocol and found that a multipath routing protocol is robust and fault tolerant. Authors in [12] have proposed a multipath based on Genetic Algorithm with energy efficiency. The motivations [14] of multipath routing in WSN are reliability and fault tolerance, energy consumption, load balancing, QoS improvement, and security [15]. The reliability is promoted by transmitting data redundantly through multiple paths and the effect of security attacks that target the availability, reliability and resilience of the network is decreased [16]. The energy consumption is preserved by distributing the network traffic across multiple paths, thus the network lifetime and connectivity is maximized [17]. According to [4] ensure reliable transport of data is an open challenge.

A wireless sensor network node is composed by four main units, processing unit, sensing unit, communication unit and power unit [13]. Such routing protocol for reliability development issue, have to address the energy consumption for every unit. In this paper we propose a multipath algorithm for reliability data transmission for WSN. The reliability is assured by multipath finding and routing according to energy consumption and the distance between the nodes. The proposed algorithm uses models for energy consumption and distance to assign a weight to each node in the WSN. By these constraints we ensure reliable data transmission within a reliable multiple paths. According to its weight a node decide to which neighbor to transmit data received from another node in the network.

The rest of this paper is organized as follows: section II introduces the energy consumption models used in the rest of the paper. It also introduces the relationship between distance and received signal strength indication [22] and the node weight computation approach. Section III is dedicated to detail our proposed algorithm by introducing our approach in the multipath routing. The last section conclude the paper and give some future works.

2. Node Energy and Distance Modeling

2.1. Processor Unit Energy Model

According to [18] and [19] the processing unit supports three operation states (sleep, idle and run) and five transition states. The energy consumption of processing unit E_{pu} is:

$$E_{pu} = E_{pu-state} + E_{pu-change} \tag{1}$$

With $E_{pu-state}$ is state energy consumption and $E_{pu-change}$ is the state-transition energy consumption.

Where

$$E_{pu-state} = \sum_{i=1}^{m} E_{pu-state}(i) T_{pu-state}(i) \tag{2}$$

and

$$E_{pu-change} = \sum_{j=1}^{n} N_{pu-change}(j) e_{pu-change}(j) \tag{3}$$

In equation (2) $P_{pu-state}(i)$ is the power of state i=1, ..., m(m = 3) which can be found in the processing unit reference manual, $T_{pu-state}(i)$ is the time interval in state i which is a statistical variable that can be calculated in this processing unit energy model. In equation (3) $Npu-change(j)$ is the frequency of state transition j = 1, ..., n(n = 5) and $E_{pu-change}(j)$ is the energy consumption of one-time state transition j.

2.2. Communication Unit Energy Model

For communication unit energy consumption model we adopt the model proposed in [21]. With this model we can estimate the energy needed to send a packet of n bits a distance d.

$$E_{TX}(n,d) = E_{tc}(n) + E_{amp}(n,d)$$

$$= nE_{trans} + n\varepsilon_{amp} d^{\gamma} \tag{4}$$

where E_{trans} is the needed energy to process a single bit by the communication unit, γ is the path loss exponent and equals 2 for the path loss of free space propagation and 4 for the path loss exponent for lossy environments and ε_{amp} is the transceiver's energy dissipation which can be expressed by:

$$\varepsilon_{amp} = \frac{\frac{S}{N_d} NF_{Rx} N_0 BW \left(\frac{4\pi}{\lambda}\right)^{\gamma}}{G_{ant} \eta_{amp} R_{bit}} \tag{5}$$

Where S/N_d is the signal to noise ratio at the receiver, NF_{RX} is the receiver noise figure, N_0 is the noise power spectral density, BW is the channel noise bandwidth, λ is the wavelength in meters, G_{ant} is the antenna gain, η_{amp} is the transmitter efficiency and R_{bit} is the channel data rate in bits per second. In our case of multipath approach, a node transmit packets to its N neighbors so the equation (4) becomes :

$$E_{TXMP}(M,n,d) = NE_{TX}(n,d) \tag{6}$$

In addition we consider that the energy needed to receive and process n bits packet is the same as in sending mode, so it can be expressed by:

$$E_{RXMP}(n,d) = E_{TX}(n,d) \quad (7)$$

and

$$E_{RXMP}(N,n,d) = NE_{RX}(n,d) \quad (8)$$

So the total energy needed to receive and send a packet is:

$$E_{total-TXRXMP}(N,n,d) = 2NE_{RX}(n,d)$$
$$= 2NE_{TX}(n,d) \quad (9)$$

2.3. Distannce and Received Signal Strength Indication RSSI

RSSI is a technique used in WSN to positioning a node in the network, using received signal strength indication [22]. This technique is also able to reduce error farthest [21]. The principle of RSSI describes the relationship between distance among nodes and transmitted and received power of wireless signals. This relation is important to achieve the reliability of WSN. In this paper we consider a free-space model and the RSSI from [22] as follows:

$$\frac{P_r}{P_t}(d) = \frac{G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \quad (10)$$

where G_t and G_r are antenna gain, λ is the carrier wavelength and L is system loss factor, according to [22] $G_t = 1$, G_r and $L = 1$ are usually taken, so the equation (10) can be writen as:

$$\frac{P_r}{P_t}(d) = \frac{\lambda^2}{(4\pi)^2 d^2} \quad (11)$$

2.4. Weight Node Computation

For a WSN node N we assign a three component vector $N = (n_1, n_2, n_3)$, where the first component n_1 is the value of the processing unit energy consumption, computed according to the equation (1). The second component n_2 represents the total energy consumption needed to receive and send a packet to neighbor nodes in the network, it is computed using the equation (9). The last component n_3 is the RSSI rate computed according to the equation (11). Let w_N the weight associated with the vector N which is computed as follows:

$$w_N = \sqrt{n_1^2 + n_2^2 + n_3^2} \quad (12)$$

3. The Proposed Multipath Algorithm

This section details our proposed algorithm, it is composed by two phases, the first subsection details the multipath construction process. The last subsection details the multipath data transmission algorithm.

3.1. Construction Phase

The first steep of our proposed algorithm is to assign to each node in the network a weight according to (12). Then the nodes broadcast the obtained weights to their neighbors. The format of the weight packet is shown in figure 1. The source node ID is the ID of the node which broadcast the weight setup packet. Destination node ID is the node ID destination. Sink node ID is the ID of the sink node. The packet type field indicates the type of the packet and that contains one of two values weight setup or data. The Sequence number contains the packet sequence. The node weight is the weight of the node which is initialized with 0. During this phase the main work is weight calculation and distribution in which the weight is broadcasted to the nodes neighbors. After the reception of neighbors wieghts the receiver node save and sort them in a key-value sorted list according to the neighbors weights. The key-value sorted list of weights contains the node ID and its associated weight. If a bigger weight is received later, then it is inserted to the top of the sorted list of weights. The sink node broadcast a packet weight setup and it will be received by sensor nodes within its range radio. The node received the packet setup compute its weight and rebroadcast it to its neighbors. When a node receive a packet weight setup it saves the received weight in its sorted list of weights. The process continue until all nodes in the network setup their weights. Algorithm 1 shows the mechanism of setting up the nodes weights.

Source node ID	Destination node ID	Sink node ID	Type	Seq. number	Node weight

Figure 1. *Weight setup packet format.*

Algorithm 1: Construction phase algorithm

```
Sink node broadcast packet weight setup.
repeat
    Sensor node receive packet weight setup.
    Sensor node compute its weight.
    Rebroadcast packet weight setup to the neighbors.
until All nodes weights seted up.
```

Figure 2. *Algorithm for the construction phase of the multipath routing protocol.*

Algorithm 2: Data transmission algorithm

```
Source node broadcast data packet with its weight
neighbors list.
repeat
    Eliminate the neighbors of the sender node from
    the weight list.
    Rebroadcast the data packet to the neighbors in
    the weight list.
until Node is sink
Sink node process the data packet.
```

Figure 3. *Algorithm for data transmission phase of the multipath routing protocol.*

3.2. Data Transmission

After the construction phase each node in the network has its weight and sorted weights of its neighbors. A source node can now transmit a packet to its neighbors with the highest weight in the sorted weights list. The neighbors around the source node receive the data packet and rebroadcast it to its neighbors with high weights by illiminating the common neighbors with the node sender. The processes continu until the packet reach its destination. The data transmission algorithm is shown in the algorithm 2.

4. Conclusion

In this paper, we propose an algorithm for reliable data transmission in a WSN. The proposed algorithm is based on multipath principle. It also take care about the constraints of the energy consumption according to the sensor node components and the distance that separate each node to another one. As a future work, we will implement and simulate the proposed algorithm to evaluate its performance and compare it with other proposed routing protocols to see he improved efficiency of the proposed algorithm.

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