



# Load-Balanced Delivery Strategy for Linear Wireless Sensor Networks

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**Abstract.** Linear Wireless Sensor Networks (LWSN) play an important role in bridge healthy monitoring, such as vibration, deformation, stress and so on. It is basically based on the observation that energy balance and delivery rate directly determine the running time of the networks. So, we proposed an energy balance aggregate model. Specially, we first compute the energy consumption and data delivery of each node in the network according to LWSN network model. The calculation conditions of energy balancing and delivery rate are then obtained. Finally, we have tested the performance of the proposed model. Simulation experimental results demonstrate that the proposed method can produce reliable performance, which is suitable for bridge healthy monitoring.

**Keywords:** Linear Wireless Sensor Networks · Bridge healthy monitoring · Energy balance · Delivery rate

## 1 Introduction

Bridge real-time online monitoring and state evaluation can ensure the safety of the bridge and extend its service life. Wireless sensor network (WSN) plays an important role in bridge health monitoring, such as vibration, deformation, stress and so on. WSN is generally characterized by a set of sensor nodes deployed in resource constrained fixed area [1, 2]. The collection nodes sense a specific characteristic phenomenon in bridge health monitoring and route the collected data to a relatively small number of sink nodes for processing and analyzing. The bridge health monitoring based on WSN is a time-consuming process, the speed and balance of energy consumption directly determine the running time of the networks [3–5].

Up to now, many energy balancing approaches have been presented to pursue the best trade-off between the different energy-consuming activities. Such as, Kacimi et al. [6] used lifetime maximizing for optimization of nodes energy consumption to improve network performance. To eliminate collisions and obtain a bound on the time required to complete converge-cast, TDMA scheduling algorithms has widely concerned, which are introduced under WSN-based framework [7–10]. Liu et al. [11] used TDMA scheduling algorithm for general k-hop networks, which aim to maximize network lifetime through optimal and selecting hop-count, and the number of timeslots. These methods

were exploited on the basis of energy balancing strategies and thus achieve fairly high performance. However, in most cases, delivery rate is ignored. We proposed a model which considering both delivery rate and energy balancing based on LWSN for bridge health monitoring.

## 2 Method

In the simplified LWSN, there are several standard nodes and one sink node, the standard nodes deliver the data to the sink node through the wireless link, which is shown in Fig. 1. In the process of data delivery, the standard node forwards the data to the sink node through any node. Suppose that in LSWN, node  $i$  needs to deliver  $N$  packets to the sink node in unit time, where the location of the sink node is denoted as  $s$ , and the probability of sending packets to neighbor node  $j$  is represented by  $p_{ij}$ , the probability of successful delivery is  $q_{ij}$ . Each node needs to receive and forward in the whole LWSN is denoted as follows:

The number of packets sent by node  $j$  is denoted and computed by,

$$N_{Tj} = N + \sum_{i=1}^j p_{ij} N_{Ti} \tag{1}$$

The number of packets received is calculated and indicated by,

$$N_{Rj} = \sum_{i=1}^j p_{ij} N_{Ti} \tag{2}$$

The total number of packets sent and received by node  $j$  is represented by,

$$N_j = N_{Tj} + N_{Rj} = N + 2 \sum_{i=1}^j p_{ij} N_{Ti} \tag{3}$$

The number delivered by the  $i$ th node to the sink node is as,

$$N_{Di} = N \left( p_{is} q_{is} + \sum_{j=i+1}^{s-1} p_{ij} Q_{js} \right) \tag{4}$$

where  $Q_{(s-1)s} = p_{(s-1)s} q_{(s-1)s}$ .

In order to achieve energy balance, lower total energy consumption and higher delivery rate, the following relationships need to be met:

- (1)  $\max(|N_i - N_j|) < \alpha$ , where  $i \neq j$  and  $j = 1, 2, 3 \dots s - 1$ .
- (2)  $\sum_{i=1}^s N_i < \beta$
- (3)  $\sum_{i=1}^s N_{Di} > \gamma$

In general, the smaller the values of  $\alpha$  and  $\beta$  show better, the larger the values of  $\gamma$  denotes better quality. When the total amount of node delivery is as small as possible, the smaller the difference in energy consumption between each node show the better. Due to the delivery rate of data decreases exponentially according to the distance between nodes, the farther the transmission distance, the lower the delivery success rate of data. We need to consider the delivery rate of data as well as the node delivery rate.

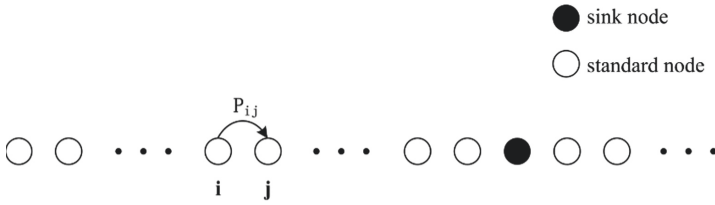


Fig. 1. LWSN network topology

### 3 Experimental Results and Analysis

#### 3.1 Subjective Evaluation Analysis

The experimental network topology is shown in the Fig. 2. We present a network with four acquisition nodes and one sink node. Each acquisition node can communicate with two neighbour nodes. We set each standard node to transmit 1000 packets to the sink node, and the delivery rates of the two neighbour nodes are 1 and 0.8 respectively. At the interval of 0.1, the transmission probability of each acquisition node to the neighbour node is traversed, and the final delivery rate and energy consumption of the node are counted, so as to find the optimal link aggregation process.

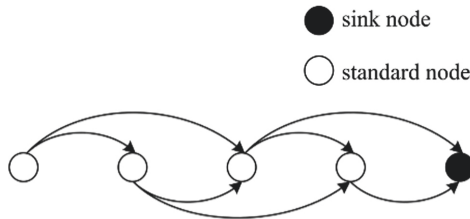


Fig. 2. Experiment topology.

#### 3.2 Performance Evaluation

The simulation results are shown in Fig. 3. The abscissa represents the normalized variance of node energy consumption, which is used to represent the energy balance between nodes, “o” represents the delivery rate value of nodes, and “\*” represents the total normalized energy consumption. It can be seen from the figure that the minimum total energy consumption is directly proportional to the delivery rate under the condition that the energy consumption difference of the whole node is small.

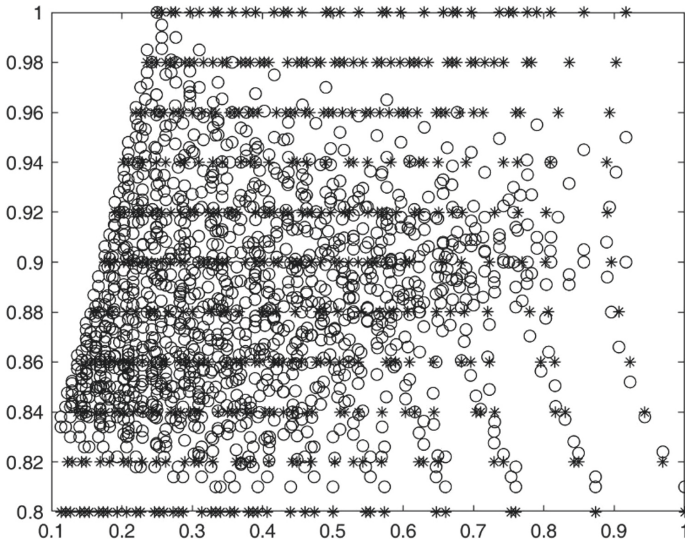


Fig. 3. Simulation results.

## 4 Conclusion

Energy balance and delivery rate are key determinant in Linear Wireless Sensor Networks for bridge healthy monitoring. Building computational models to estimate energy balance and delivery rate is thus of great importance. In this paper, we proposed an energy balance aggregate model. To this end, according to LWSN network model, energy consumption and data delivery of each node in the network are first computed. Then we give calculation conditions of energy balancing and delivery rate. Finally, we have tested the performance of the proposed model. Simulation experimental results demonstrate that the proposed method can produce reliable performance, which is suitable for bridge healthy monitoring.

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