A Lightweight Interference Measurement Algorithm for Wireless Sensor Networks

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Abstract. The most applications of wireless sensor network have stringent requirements for communication performance. To meet applications requirements, it is crucial to measure the wireless interference between nodes, which is the major factor that reduces the performance of wireless sensor networks (WSNs). However, the key problem of accurately measuring wireless interference is that the node cannot predict the neighbor node information after the network is deployed, and thus cannot establish the correspondence between the wireless interference strength and the neighbor node. To tackle this problem, this paper presents a lightweight interference measurement algorithm for WSNs. The algorithm divides the interference measurement process into three phases. The first two phases are used to gather all two-hop neighbor information by exchanging between nodes. In the third phase, each node performs interference measurements and builds the relationship of wireless interference between nodes. The experimental results show that our proposed approaches can obtain accurate inter-node wireless interference strength with low energy and communication overhead.

1 Introduction

Wireless sensor networks have been widely used in transportation, agriculture, construction, military and other fields. Most wireless sensor network applications impose strict requirements on communication performance. In general, wireless sensor nodes are interconnected by wireless links and self-organized to form an interconnected network. Due to the broadcastability of the wireless channel, the data transmission of the node will cause significant wireless interference to its neighboring nodes, then affecting the data transmission of its neighbor nodes, thereby reducing the network transmission efficiency and increasing the data transmission delay. For wireless sensor network applications, accurate measurement of wireless interference between nodes is the key to improve communication

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performance. Due to the limited communication and computing power of wireless sensor nodes, it is challenging to achieve accurate measurement of wireless interference of nodes with lower energy and communication overhead.

Early research on wireless interference focused on modeling the relationship between wireless interference and packet reception ratio(PRR). Usually, the paper studies the wireless interference between several nodes and constructs wireless interference model, such as SINR-PRR [1–3]. By using these research results, the scheduling of node data transmission can be realized, thereby improving the communication performance of link scheduling, media access control, and routing protocols [3–5]. Since the wireless interference model constructed based on the small-scale sensor test network, the wireless interference model can effectively improve the communication performance in a network environment similar to the experiment. However, when extended to large-scale sensor networks, the node's wireless interference environment is very complex, and the link status between nodes is time-varying. The adaptability of wireless interference models cannot be effectively guaranteed. Therefore, the run-time measurement of wireless interference is one of the feasible solutions to solve the wireless interference model's adaptability to the network environment.

Based on the TDMA protocol, the paper combines the node ID with the time slot allocation by using the unique ID of the node in the network. Each node has a unique time slot, which ensures that the wireless interference of the node can be accurately measured and recorded. The algorithm divides the interference measurement process into three phases. The first two phases complete the information collection of the two-hop neighbor nodes through the information exchange of neighbor nodes. Each node broadcasts in its own time slot in the third phase, and the neighbor nodes complete the measurement of the wireless interference strength by monitoring the wireless channel. After all nodes complete the broadcast, each node can accurately construct a wireless interference matrix based on the result of interference measurement. Based on this, more reliable node transmission activity scheduling and network performance optimization can be realized.

2 Related Work

Since Gupta and Kumar [6] proposed an accurate interference model for wireless networks, there are many works were carried out for researching the behavior of interference in wireless networks. In this section, we review these related work.

Zhao's work [7] showed that the communication links are often lossy and asymmetric. In [8], the author proposed a calculation model to compute interference levels in wireless multi-hop ad-hoc networks. The object of the model is to calculate the expected value of carrier to interference ratio (C/I) and evaluate performance of mobile wireless ad-hoc networks. The relationship of wireless interference and path reception ratio is referred in [9]. The author show that the average signal to noise and interference ratio (SINR) either remains constant , or decays when the number of interferers scales to infinity in the network. In order to understand the role of interference on the overall performance of wireless networks, Razak et al. [10] show that the number of scenarios of two-flow interaction is very larger when relax the assumption that the wireless interference range is equal to the receipting range.

Unlike the previous works, some works study the interference by examples. Subbu et al. [11] examines the impact of collocated 802.15.4 devices on each other by observing the effect of interfering device on the desired device in terms of packet error rate (PER). The author want to understand how and when 802.15.4 may impact each others performance. In [12], the author experimentally investigate the effects of WLAN and realistic RF interference on packet delivery performance in body area networks (BANs). Rahul et al. [13] propose a approach to detecting and mitigation interference occurs in two different ZigBee networks. When interference happened, the protocol leverages collaboration between interfering networks to determine which network should switch to a different channel. Interference also can be used to discovery wireless LAN, and a interesting approach is described in [14].

3 Interference Measurement Algorithm

Consider a homogeneous sensor network that is composed of a single base station (BS) and N sensors are randomly distributed in a monitoring area. We use $S = s_1, s_2, \ldots, s_n$ to denote the set of sensors. Each node has the same initial energy. For node i and node j, the communication is reliable iff the distance $d_{ij} \leq d_o$, otherwise, there is only wireless interference between two nodes. d_o was defined in [15]. For simplity, we only considers wireless inteference measurements within two hops.

The problem to be solved in this paper is described as follows: In a given wireless sensor network, for any node i in the network, it is assumed that the set of one-hop and two-hop neighbor set are represented by L_1 and L_2, respectively. The interference measurement algorithm can be used to accurately measure the two-way wireless interference strength between the node and any of the node in $L_1 \cup L_2$, while the algorithm has lower time and energy overhead.

The paper designs a TDMA-based interference measurement algorithm. Each node is assigned a unique time slot, and the ID of the node is the time slot assigned to the node, and the ID is begin with 1. The node transmits data only when its time slot arrives, otherwise it switchs to the listening state. In order to ensure that the proposed algorithm can be executed correctly, clock synchronization is necessary between nodes. Many efficient clock synchronization mechanisms can be combined with our algorithm, such as TPSN [16]. For the sake of discussion, this article assumes that all nodes have completed clock synchronization. The algorithm consists of three phases: the first phase is used to complete the information collection of the one-hop neighbor node and the partial two-hop neighbor node; the second phase is executed to improve the information of the two-hop neighbor node; finally, the node interference measurement is finished in the third phase, and each node can construct a local interference matrix after completing the interference measurement.

The first stage: one-hop neighbor node information collection. Since the ID number of each node in the network is unique, the time slot $slot_i$ assigned to the node i can calculate using Eq. 1.

$$slot_i = (s_{id} - 1) * t_{slot} + t_{init} \quad (1)$$

where $slot_i$ represents the ID of the node i, t_{slot} represents the length of the time slot, and t_{init} represents the start time of the first phase. Note that in order to ensure that our algorithm can perform normally, the setting of t_{init} should take into account the time of network deployment.

After completing the slot calculation, each node broadcasts the node's neighbor information N_{info} to its one-hop range in its time slot. The node will then stay in the listening state for the remaining time slots of this phase to receive neighbor information broadcast by its neighbor nodes. The generation and update process of the one-hop neighbor information table is shown in Fig. 1.

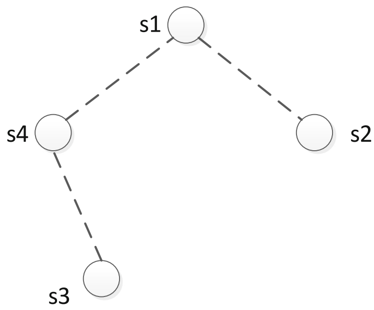

Fig. 1. The network topology of our illusration

The dashed line between nodes is just to indicate the neighbor relationship. It can be concluded that the one-hop and two-hop neighbor relationships of node s1 can be represented by the set: $L_1 = (s2, s4)$ and $L_2 = (s3)$, respectively. According to time slot arrangement method, the time slots of the nodes $s1$, $s2$, $s3$, and $s4$ are $slot_1$, $slot_2$, $slot_3$, and $slot_4$, respectively. Therefore, node $s1$ will first broadcast its neighbor information N_{info}. The N_{info} contains $s1$'s slot information and the partial one-hop neighbor time slot information that it has collected so far. At this time, the neighbor information N_{info} of $s1$ is shown in Table 1.

Since there is no radio interference and is located within the effective communication range of the node $s1$, the neighbor nodes $s2$, $s4$ can correctly receive the neighbor information of the node $s1$ and construct its own neighbor information table. The neighbor information tables of nodes $s2$ and $s4$ are shown in Tables 2 and 3, respectively.

Table 1. The $s1$'s neighbor information

s_{id}	$s1$
t_{slot}	1
hop	0

Table 2. The $s2$'s neighbor information

s_{id}	$s1$	$s2$
t_{slot}	1	2
hop	1	0

Table 3. The $s4$'s neighbor information

s_{id}	$s1$	$s4$
t_{slot}	1	4
hop	1	0

Next, the node $s2$ broadcasts its neighbor information in the time slot 2. For the same reason, the node $s1$ will be able to correctly receive the neighbor information of $s2$, and after updating based on the the neighbor information of $s2$, the neighbor information of s1 is as shown in the Table 4.

Table 4. The updated $s1$'s neighbor information

s_{id}	$s1$	$s2$
t_{slot}	1	2
hop	0	1

According to the time slot arrangement, the node $s3$ broadcasts its neighbor information during the time slot 3, the node $s4$ receives the neighbor information of $s3$, and after updating based on this information, the neighbor information of $s4$ is shown in Table 5.

Table 5. The updated $s4$'s neighbor information

s_{id}	$s1$	$s3$	$s4$
t_{slot}	1	2	4
hop	1	1	0

Finally, $s4$ broadcasts its neighbor information in time slot 4. The nodes $s1$ and $s3$ receive the neighbor information of s4 and update according to it. The updated neighbor information of $s1$ and $s4$ are Tables 6 and 7, respectively.

Table 6. The updated $s1$'s neighbor information

s_{id}	$s1$	$s2$	$s3$	$s4$
t_{slot}	1	2	3	4
hop	0	1	2	1

Table 7. The updated $s3$'s neighbor information

s_{id}	$s1$	$s3$	$s4$
t_{slot}	1	3	4
hop	2	0	1

In the first phase, the node collects some two-hop neighbor information, such as nodes $s1$ and $s3$. However, since $s1$ finished the neighbor information broadcast before $s2$ and $s4$, $s2$ and $s4$ cannot successfully collect the two-hop neighbor information related to $s1$. In order to solve this problem, the algorithm will execute the second phase to improve the two-hop neighbor information of all nodes.

In the first phase, each node uses only one time slot, so the duration of the first phase is $N * t_{slot}$.

The second stage: the exchange and update of two-hop neighbor information. This phase is mainly used to improve the two-hop neighbor information of all nodes. In order to ensure the smooth progress of the second phase, we have $t_{init} = N * t_{slot} + t_{gap}$, where t_{gap} is mainly used to ensure that the second phase can start correctly. Therefore, in the second phase, the time slot of the node is calculated using Eq. 2.

$$slot_t = (s_{id} - 1) * t_{slot} + N * t_{slot} + t_{gap} \tag{2}$$

Each node broadcasts neighbor information according to the allocated time slot. After the second phase is executed, all nodes can obtain complete one-hop and two-hop neighbor information. For example, nodes $s2$, $s4$ will receive the neighbor information broadcast by node $s1$ in time slot 1. After the neighbor information table is updated, the neighbor information of the nodes $s2$ and $s4$ are shown in Tables 8 and 9.

In this phase, since each node occupies one time slot, the duration of this phase is $N * t_{slot}$.

The third phase: the node performs interference measurement and constructs a local interference matrix. The node will listen to the wireless channel according

Table 8. The updated $s2$'s neighbor information

s_{id}	$s1$	$s2$	$s4$
t_{slot}	1	2	4
hop	1	0	2

Table 9. The updated $s4$'s neighbor information

s_{id}	$s1$	$s2$	$s3$	$s4$
t_{slot}	1	2	3	4
hop	1	2	1	0

to its neighbor information to measure the wireless interference strength related to the neighbor node, and then switch into sleep model until the active time slot of neighbor node arrives. In the third phase, the initial time of the node slot is $t_{init} = 2 * N * t_{slot} + t_{gap}$, and the slot of each node is set by equation (3).

$$slot_t = (s_{id} - 1) * t_{slot} + 2 * N * t_{slot} + t_{gap} \tag{3}$$

After the interference measurement is completed, each node will construct an interference matrix as shown in Table 10 (for example, 50 nodes are randomly deployed in a 100 m × 100 m area. The wireless signal propagation model is Two Ray model).

Table 10. A node's interference matrix (db)

s_{id}	$s6$	$s8$	$s15$	13
Strength	–23.5	–23.1	–26.5	–13.6
hop	2	2	2	1

4 Numerical Results

We evaluate our interference measurement algorithm by simulation examples with random network has different diameter and the amount of nodes. The energy model we used is described in [15]. The energy model is expressed as follows:

$$\begin{aligned} E_{Tx}(P_l, d) &= P_l E_e + P_l \varepsilon_{fs} d^2 \\ E_{Rx}(P_l, d) &= P_l E_e \end{aligned} \tag{4}$$

where P_l denotes the size of packet, the default value is 1000 bits. E_e denotes the energy consumed by the circuit when transmitting and receiving data, the

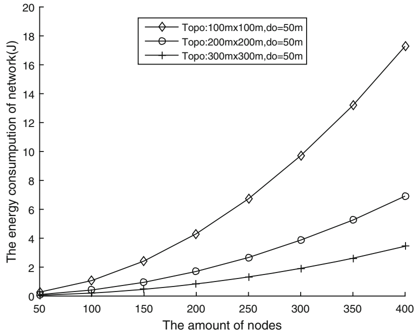

Fig. 2. The network energy consumption vs the amount of nodes

default value is 50 nJ/bit. ε_{fs} is the power loss factor, the default value is 0.0013 (pJ/bit)/m^4. d denotes the communication distance between two nodes, and $d \leq d_o$.

Figure 2 shows the relationship between network energy consumption and the number of nodes. In all experiments, the node effective communication distance d_o is set to 50 m. It can be seen from the figure that when the network has the same number of nodes, changing the network coverage (from 100 m $\times$ 100 m to 300 $\times$ 300 m) will reduce the total energy consumption of the interference measurement, which means that distributing the nodes in a wider area will reduce the node density, thus Reduce interference measurement energy consumption. For the same reason, for the same network topology, for example, 100 m $\times$ 100 m, changing the number of nodes significantly increases the energy consumption of the interference measurement.

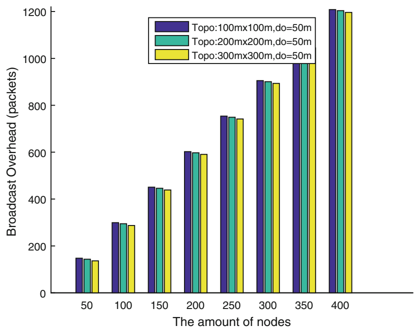

Fig. 3. The communication overhead vs the amount of nodes

Figure 3 shows the relationship between the number of nodes and communication overhead. The effective communication distance d_o is set to 50 m. It can be seen from the figure that as the number of nodes increases, the number of packets that need to be broadcasted to complete the interference measurement also increases significantly, and the total number of packets is basically three times the number of nodes. This is basically in line with the theoretical results of the interference measurement algorithm in this paper.

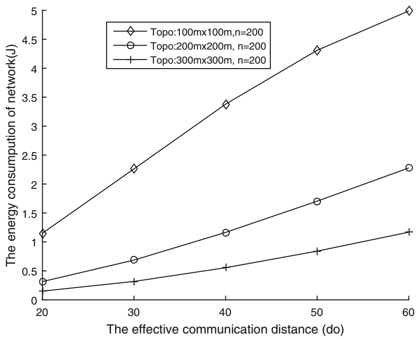

Fig. 4. The energy consumption vs effective communication distance

Figure 4 shows the relationship between communication distance *do* and network energy consumption. It can be concluded that the increase of the effective communication distance of the node will increase the number of neighbor nodes, thereby significantly increasing the energy consumption. For a network with a high node density, for example, deploying 400 nodes in a 100 m × 100 m area, the energy consumption is significantly higher than that of the other two scales, and the energy consumption is nearly five times different. This shows that the interference measurement algorithm is not suitable for networks with high node density.

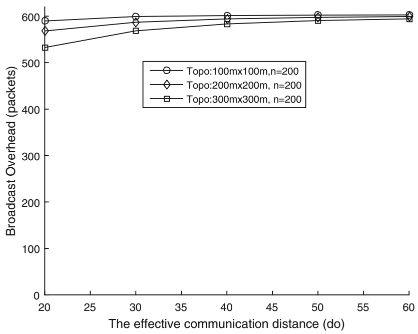

Fig. 5. Communication overhead vs effective communication distance

Figure 5 shows the relationship between effective communication distance and network communication overhead. It can be concluded from the figure that for networks of different network sizes, when the communication distance of nodes increases, the difference in broadcast overhead of the algorithm will gradually become smaller. The reason is that the increase of the communication distance of the node will lead to an increase in the number of neighbor nodes, and more neighbor information can be obtained by the broadcast of the node, so that the node can obtain complete neighbor node information, and the node that broadcasts in the second stage is reduced. Then, the broadcast overhead of the network is reduced.

It is worth noting that, as shown in Figs. 4 and 5, under the same communication distance, the difference between the broadcast overheads of different networks is gradually decreasing, and the difference in energy consumption is significantly increased, which indicates that the large energy consumption is consumption during the interference measurement phase. As the communication distance increases, the number of neighbor nodes of the node increases, and the number of times the node needs to detect the interference strength will increase significantly, resulting in an increase in node energy consumption.

5 Conclusion

The paper proposes a lightweight interference measurement algorithm. The algorithm divides the interference measurement process into three phases. The first two phases realize the information exchange and collection of the two-hop neighbor nodes by letting the nodes schedule the broadcasts according to the time slots, and provide complete neighbor node information for the third-stage interference measurement. In the third phase, each node broadcasts an interference measurement packet in its own time slot, and monitors the wireless signal strength in the neighbor node time slot, and completes the measurement and acquisition of the neighbor node interference strength. The accurate measurement results provided by the algorithm can be used for network transmission activity scheduling of nodes, which can achieve reliable concurrency of data transmission activities between nodes, thereby improving network efficiency and reducing transmission delay.

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