P(4, 4) and the receiver will receive the next probe packet and calculate the burstiness value. Assume that next time the probe packet is P(4, 7), so the burstiness value also 2, the burstiness time count will be increased by 1 value to describe that the burstiness value 2 is duplicated. Let the result of transmission per link at ith sequence if successful is “S” and “F” if failed transmission. With the above example of node 1 and node 4, we have the result of the transmission after 7 probe packet is “SFFSFFS”. After finish the measure link quality period (MLQ), we have a BDL of a link with 1000 probe packets transmission in Table 1.

Table 1. Burstiness Distribution List (BDL) of a link after finish MLQ.

Burstiness value	0	1	2	3	4
Burstiness time count	634	129	31	2	1

Let make the relationship between the burstiness value and burstiness time count in BDL. The burstiness value is defined as the number of consecutive loss during probe packets transmission, and the burstiness time count has defined the time burstiness value happen. For example, in Table 1, after 1000 probe packets transmission, burstiness value 0 happens 634 times, burstiness value 1 happens 129 times, and so on. It means that in 1000 probe packets transmitted, 634 times happens the result of transmission is “SS”, 129 times happen the result of transmission is “SFS”, …With the link has good quality, the burstiness value will be small while the burstiness time count will be large at min burstiness value. On the contrary, the bad link has a higher burstiness value and low burstiness time count at min burstiness value.

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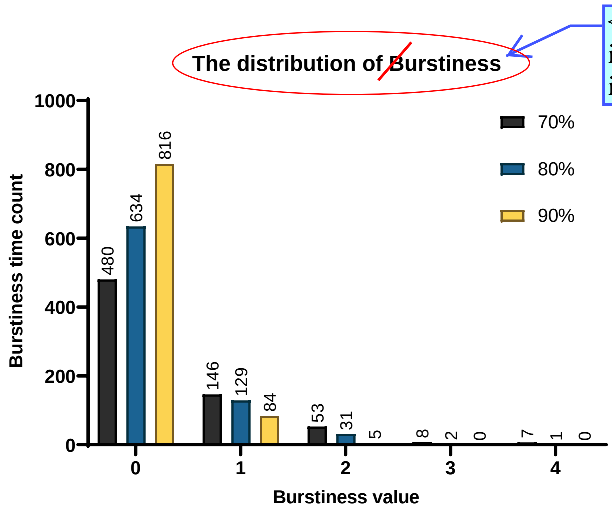


Figure 2. The distribution of Burstiness compares with link PRR.

For example, Figure 2 shows the simulation result of one pair of nodes with the different configured of the PRR value. The distribution of the burstiness value compare with link PRR 70%, 80%, and 90% with the number of probes is 1000 packets in Figure 2 describe that with the good link (PRR 90%) has the burstiness time count with min burstiness value is 816 and max burstiness value is 2. On the other hand, the bad link quality (PRR 70%) has the burstiness time count with a min burstiness value is 480 and the max burstiness value is 4.

3.3. Burstiness Distribution Metric

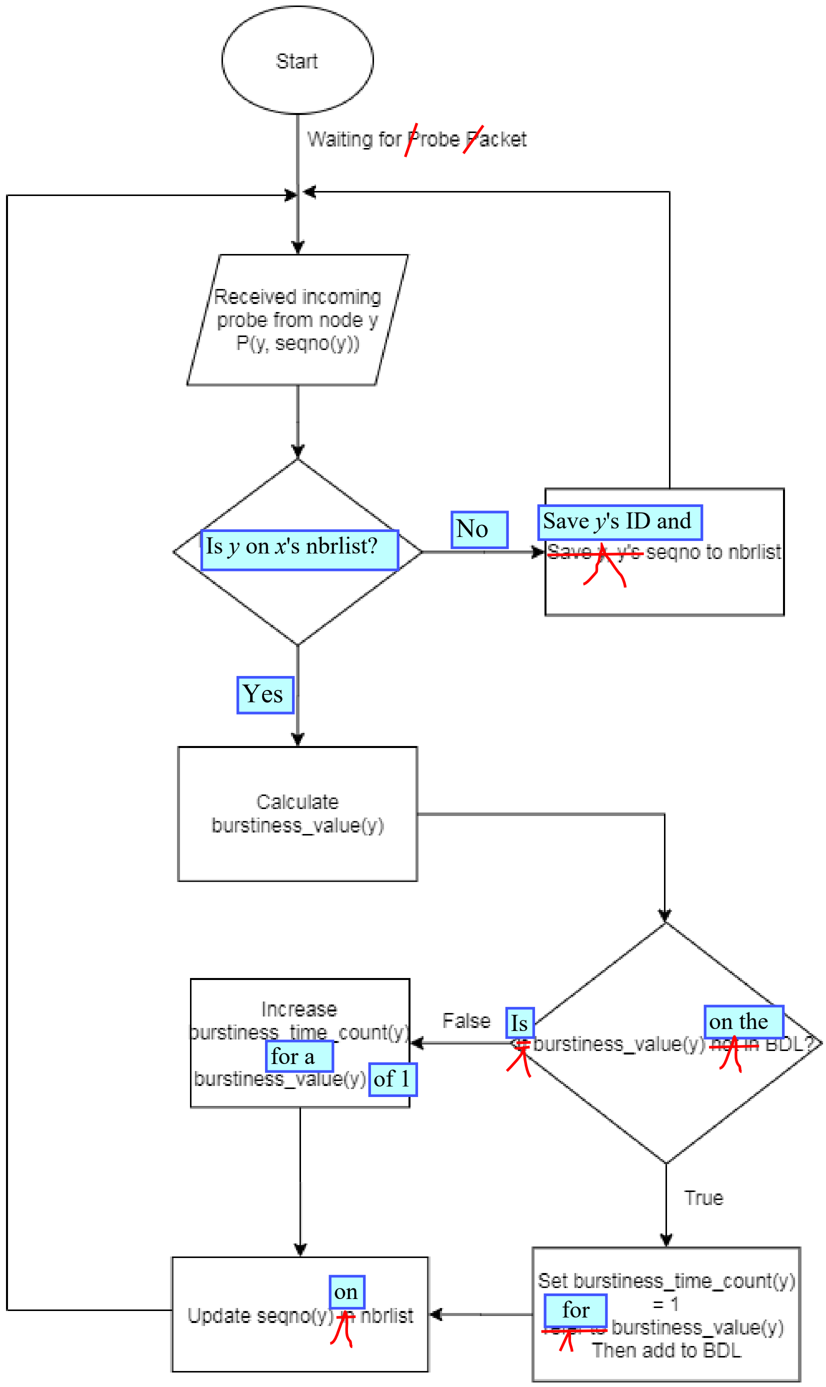
In this section, we present a scheme to calculate the number of retransmissions by Burstiness Distribution List (BDL) with named Burstiness Distribution Metric (Bdist).Firstly, the neighbor list (nbrlist) and the BDL are set to empty. When the sensor node, called *x*, received a probe packet from node y, it saves node *y* and node *y's* sequence to its nbrlist if node *y* does not belong to node *x*'s nbrlist. If node *y* has belonged in node *x*'s nbrlist, node x will calculate the burstiness value refer to node y as follows:

burstiness_value (y) = seqno(y) – nbrlist[y].seqno(y) - 1

in which, seqno(y) is the sequence number get from new incoming probe packet from node y, nbrlist[y].seqno(y) is the previous sequence number of node y saved in the neighbor list.

The burstiness_time_count(y) refer to burtiness_value(y) set to 1 and the pair (burstiness_value(y), burstiness_time_count(y)) will be saved in node y's BDL if this value does not belong to node y's BDL. If burtiness_value(y) is belong to node y's BDL, node x will increase the burtiness_time_count(y) refer to burstiness_value(y) one. Then update the seqno(y) value in the neighbor list.

This process will repeat during the measure link quality period. The detailed algorithm is described in Algorithm 1 and the flowchart in Figure 3.



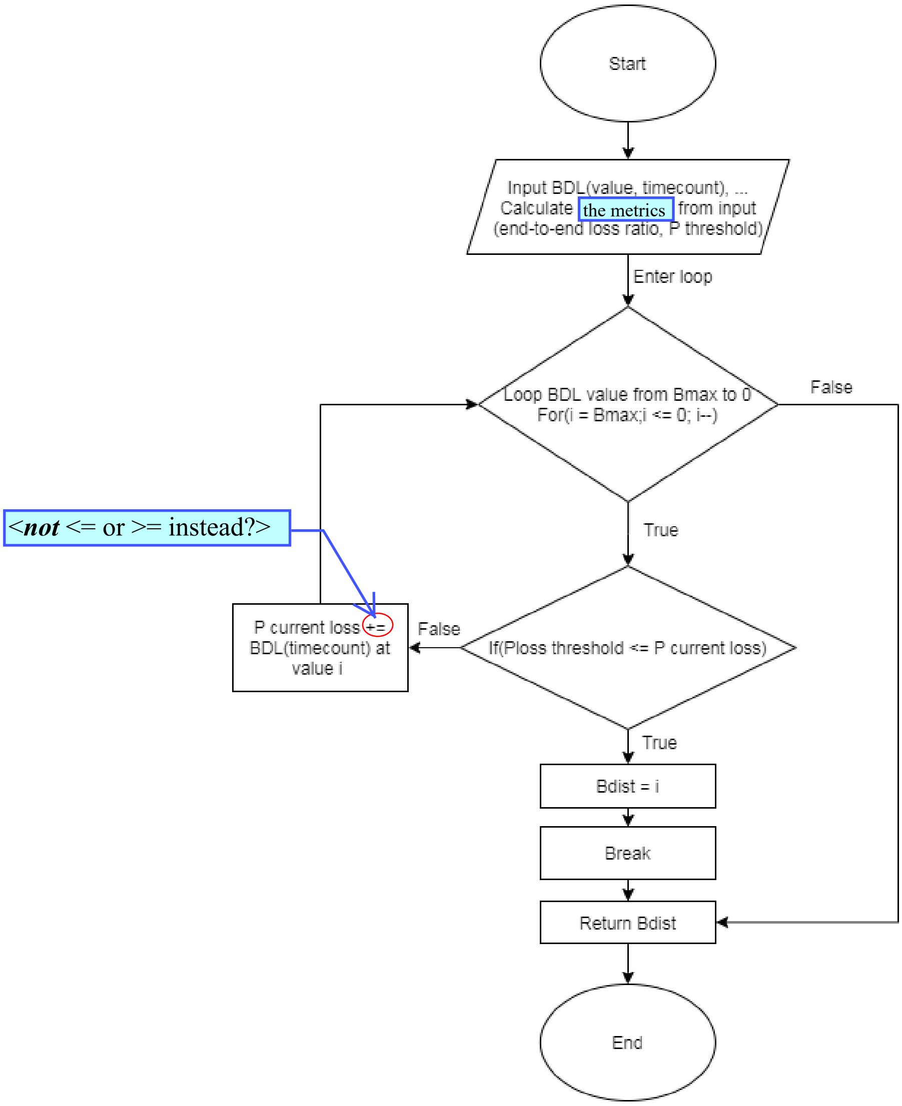


Figure 4. The flowchart of the main procedures of Algorithm 2.

4. Evaluation

By using Cooja Simulator, the Bdist is compared with some schemes such as ETX, PRR. The key parameter is present in Table 2.

Table 2. Summary of the simulation set up parameters.

Number of nodes	10
Number of probes	1000
Target PRR	99%
Link quality of the channel (is set)	70% - 90%
Number of the data packets	1000
Network area	100m x 100m
Payload size	26 bytes
Simulation time for each scenario	About 55 minutes

In which the link quality of the channel of each link indicates the number percent of the successful packet at the receiver compared with the number packet of senders. For example, if the link quality of the channel equals 70 indicate that the receiver will receive 70 packets if the sender sends 100 packets. The number of probes to measure link quality and the number of data packets to evaluate the measure link quality metric are 1000 packets.

4.1. Relationship of the number of retransmissions and network performance

To evaluate the effect of the number of retransmissions on the performance of the network, a simple network with one sink (gateway) and nine sensor nodes are considered. The link quality of the channel will be fixed while the number of retransmissions will be varying from 0 to 3 times and we will examine the packet reception rate at the sink with each value of the number of retransmissions.

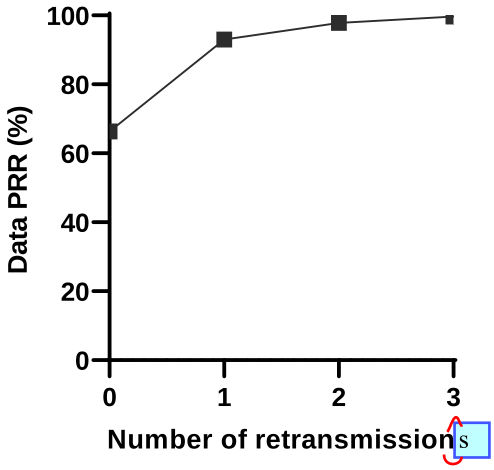


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Figure 5. Relationship of the number of retransmissions to packet reception rate.

The result in Figure 5 shows that since the sensor nodes are not allowed retransmissions, the PRR at the sink can achieve a low PRR, 66.3%. when the sensor nodes are allowed retransmission, the PRR will be improved and increased since the number of retransmissions increased. It is shown that since the link quality is not very good, the number of retransmissions will decide the network performance. Therefore, estimate the number of retransmissions is very important.

4.2. Effect of the hop count on network performance

We evaluate the effect of hop count on PRR. A simple linear network with the hop count varying from 1 to 4 is considered. In which we compare our proposed with some schemes such as ETX, PRR. Each scheme estimates the number of retransmissions by itself. We will examine the packet reception rate at the sink with each value of the hop count.

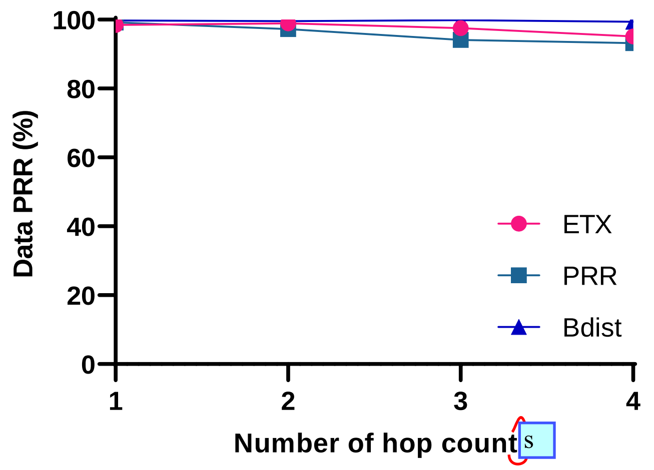

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Figure 6. Effect of the hop count on network performance.

The result is present in Figure 6. From Figure 6, we can see that our proposed archives very high PRR even at the highest hop. It is because our proposed have a good estimation of the number of retransmissions by using the target PRR, estimate link quality method. While other schemes the PRR will be decreased since the hop count in-creased. This is because the scheme to estimate the number of retransmissions of two other schemes is not very good.

4.3. Evaluate the network with some estimation scheme

In this examination, nine sensor nodes are deployed randomly and the link quality of each between two nodes is set randomly from 70% to 90%. Each sensor node will generate 1000 packets periodically. The TSCH MAC protocol is used with the PCLLF [24] scheduling algorithm to guarantee that no collision in the network. We collect the packet reception rate of each sensor node at the sink.

The result of the data PRR of each sensor node at the sink is present in Figure 7. From Figure 7, the PRR of the proposed scheme almost archives targets PRR with the estimated times of retransmission for each sensor node. It shows that the algorithm of calculating the number of retransmission work well. Furthermore, the other archives much lower PRR since the estimation of the number of retransmissions of ETX and PRR is not very good. This is because ETX and PRR did not consider the burstiness happen in the link.

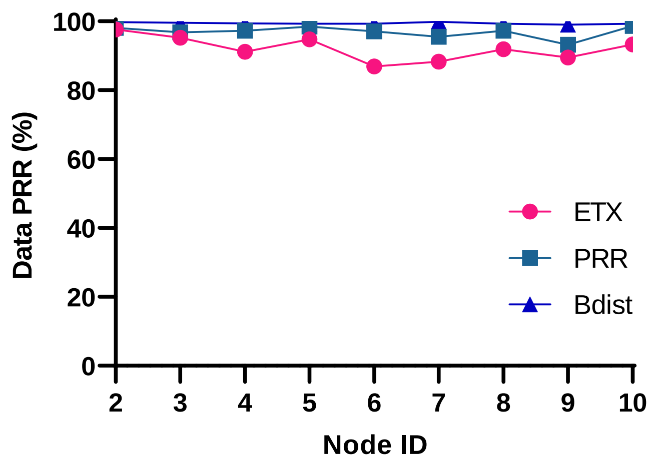

Figure 7. The data PRR of each sensor node at the sink of some estimation scheme.

4.4. Evaluate the network with some type of network