Study of Wireless Sensor Networks Routing Metric for High Reliable Transmission

Rongbiao Zhang
1. School of Electronic and Information Engineering, Jiangsu University, zhenjiang, China
Email: soyox@126.com

Yongxian Song, Fuhuan Chu and Biqi Sheng
2. School of Electronic Engineering, Huaihai Institute of Technology, Lianyungang, China

Abstract—To wireless communication, it is easy to be interrupted by all sorts of factors, such as, antenna direction, transmission power, distance, nodes voltage and so on. And the reliable transmission of data is the key problem for Wireless Sensor Networks (WSN) in recent years. In former research, there are many methods which can ensure data reliable transmission, but can not choose the best performance path and reduce the bottleneck link effectively. So, on the basis of analyzing the influence of antenna direction, transmission power, distance and nodes voltage on LQI respectively, the paper proposes a new method—link quality indication based on metric (LQIBM), which can accurately find the link with severe packet loss rate in wireless networks firstly. Second, the model of LQIBM is constructed by Combining the mean and Coefficient of Variation (C,V) of link quality appropriately. Then, the hardware experiment platform is conducted by using wireless communication chip CC2430. Compared with LQIM, the results of simulation and experiment show that LQIBM succeed in finding the best communication path that has much lower packet loss rate, the miscarriage of justice is avoided for LQIM, the path with the bottleneck link is effectively excluded, and the better reliability of the data transmission is achieved for WSN.

Index Terms—wireless sensor networks; rout metric; link quality instruction; bottleneck link; reliability.

I. INTRODUCTION

WSN has been widely applied to transmit data in environments, mines, military affairs, telemedicine, industries and other fields, and communication cannot be optional interfered or damaged [1][2], so the reliability of transmission is very important. For long-distance transmission, single-hop communication is unable to meet our needs due to the restriction of transmission distance and accuracy, so multi-hop communication is widely applied [3]. However, the link quality of a certain hop or a few hops in a chosen path may become extremely poor due to complex natural environments, and human interference or the impact of hardware itself, which make the data transmission unreliable for multi-hop, thus the unpredictable data packet loss may appear[4][5]. Nowadays, nodes are usually densely deployed in data collection regions, adjacent nodes can receive request messages from several routes, and a number of transmission paths for multi-hop are formed. It is very important significance to choose a highly reliable multi-hop path to transmit data for WSN.

In recent years, lots of scholars continually have been studied on reliable data transmission in wireless network at home and abroad. In order to improve reliability, the redundancy or retransmission is often adopted for traditional methods. Hao Wen et al. compared the two methods, and find that redundancy is better than retransmission in lower packet loss rate (PLR), and the two methods are effective only when the link quality is good. But when PLR is quite higher, it means that the communication link has been in poor quality, and performance of the two methods declines significantly. Therefore, even though there is a large number of redundancy or retransmission, the high reliability of data transmission cannot be guaranteed too [6]. Jeongycop Paek et al. avoided channel congestion by controlling data transmission rate to improve the reliability, and solved the congestion problem that caused by transmitting lots of data to one or more sink nodes [7]. Shoubhik Mukhopadhyay et al. have put forward a new method of reliable transmission based on data prediction model. According to the time correlation, the data prediction model is built, and it is used to correct real-time errors. The transient faults for nodes and wireless channel can be promptly corrected by the above method too, but it is a post-correction approach [8]. Ali Tufail et al. chose a reliable path by adding gateway nodes in networks, and replace a part of wireless transmission with the wired transmission among gateway nodes, so as to achieve end-to-end reliable transmission [9]. In order to find a high reliable path, people also have made many studies on routing metric to evaluate paths in the network. Such as, Packet Reception Rate (PRR) can estimate link quality effectively, and find a reliable path to transmit data. But the calculation of PRR need measure many samples, and lots of energy and bandwidth are wasted [10]. The greatest advantage of Minimum hop count (MHC) is its simplicity, but the link quality doesn’t be considered, so the link quality may poor for the path that

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was chosen, the packet loss rate is very high, and the
unreliable data transmission is caused. While the
transmission doesn't need high reliability, MHC can be
well used due to its easy employment [11]. Expected
Transmission Count (ETX) and metric parameters can be
obtained in a low transmission rate, but it is no longer
applicable when data are transmitted in a higher speed
[12][13]. Round Trip Time (RTT) is metric method
based on loads, and it has the rout instability problem
which is called self-interference, and it often appears in
wired communication [14].

This paper proposes a routing metric which is based on
both Link Quality Indication (LQI) mean and Coefficient
of Variance (C.V). The quality of transmission is
evaluated by metric model in the network, in order to
find a high-quality path to transmit data and achieve a
high reliability. We know by the definition of
IEEE802.15.4 protocol that the link quality instruction
(LQI) is used to indicate the strength and quality that
receive packets. It can be measured through the receiver
energy detection and SNR estimation [15]. LQI can be
directly measured by wireless hardware CC2430 which is
produced by the Chipcon Corporation and supports
2.4GHz IEEE 802.12.4 protocol [16]. Both V. Cagri
Gungor [17] and Zhang Xiyuan [10] were taken LQI
mean as routing metric to transmit data, Packet
Reception Rate (PRR), throughput and path efficiency
reach a good effect. Reference [18] [19] adopted LQI
mean to estimate the quality of path, but they do not take
the bottleneck link problems into account.

According to the particular application background,
the definition of bottleneck link should be modified in
this paper. In the field of computer network, it refers to the
capacity that communication link loads exceed the
rated loads, and packet loss may be caused even if
communication is normal. To define communication link
paths, the quality of the other link is good, and that of a
hop or a few hop links is poor, and the average quality of
the entire path will be affected, the links are known as
bottleneck link.

In this paper, LQI mean and standard deviation are
quantified first, and the quality path is judged by the
dynamic weighting. In this way, the links with high
quality and stable performance are found to transmit data,
which can effectively avoid the appearance of bottleneck
links, congestion and retransmissions. Therefore, the rate
of transmission faults can be greatly decreased. LQI
mean is obtained through hardware measurement and
calculation, which is simple and affected by the
transmission speeds, and the link quality can effectively
be estimated under various circumstances.

II. LINK QUALITY INDICATION

A. Relationship between PRR and LQI

Packet Reception Rate (PRR) is an index that is
widely used to estimate the link quality. It can respond to
the changes of link quality rapidly, but, in order to get
accurate PRR, it needs very large sample space and a
great number of exploration expenses. With the
development of chips technology, Received Signal
Strength Indication (RSSI) and LQI have become two
most wide metric methods.

The LQI values are calculated in the MAC (Media
Access Control) layer and are provided to upper layer,
the size if the values depend on the strength of the
detected Signal to Noise Ratio (SNR). The LQI values are
always related with the correct PRR [20]. LQI can be
directly measured by hardware, it is easy to use and it is
quick to respond. Many papers have given specific
experiments in order to obtain the fitting curves between
LQI and PRR. In the reference [21], the actually
observed data are separated, and the relationship of LQI
and PRR is obtained by means of replacing continuous
function with piecewise function. Here, the data are
divided into two intervals ([54, 70] and (70, 110]), then
the fitness of curves is 0.92.

In order to the accuracy of experimental values, we did
LQI and PRR related experiments by own experimental
platform. In the same indoor, the sending node transmits
400 probe frames to the receiving node, and the PRR and
LQI mean are calculated. The output ranges of LQI
values is from 50 to 110, namely, the minimum value is
50. When the packet is lost in a wireless network, the
LQI values will be recorded as 50. Diagrammatic curve of
PRR and LQI mean is shown in Figure 1.

Figure 1 illustrates that there is a high correlation
between LQI mean and PRR, which indicates that the
LQI can accurately estimate the quality of single-hop
links. So a new routing metric is put forward, which is
based on LQI mean, and the bottleneck links can be
corrected.

B. LQI Metric and Its Influence Factor Analysis

According to the characteristics of LQI, many
researchers take LQI mean as the routing metric, which
is tentatively named as LQI metric (LQIM). Combined
with appropriate routing protocols, it can be well applied
to practice, and the communication path with higher LQI
mean is chose.

Different deployment of sensor nodes and the
complexity of the natural environment will both affect
the LQI values in some degree. Some research
demonstrated that the main factors which affect on LQI
values include obstacles, antenna, power and distance.
The obstacles restrain the coverage and connectivity of
WSN, therefore, when sensor nodes select the long-
distance paths, the more energy will be consumed, the
higher packet loss rate will appear, even the nodes are
failure. Reference [22] simulated field of WSN, defined a variety of indoor obstacles, and established model according to physical properties and size of obstacles. The results of experiment indicated that the obstacles can obviously affect the performance of LQI for a variety of routing protocols. The strength of radio frequency signal in space is much relevant to the angle of antenna, and multi-path effect always occurs when the data are transmitted [23], so the signal strength has very different in different angles. The interference can be effectively reduced by adopting an appropriate antenna for WSN, and the lower power consumption and the higher reliability are achieved too. When the transmission power is different, the wireless signal strength will be influenced, and in theory, the stronger the power is, the greater the signal strength is. Meanwhile, the transmission power also affects communication radius of nodes, the signal strength and the stability of link quality. There are many location study based on LQI for WSN, in order to analyze the impact of distance on the LQI, some experiments have been done in reference [10] [22], here, we will not repeat again.

In practice, bottleneck links always exist because of various influence factors, at the moment, the metric based on LQI mean don’t consider the volatility of the link quality, so the metric of LQIM will be no longer applicable.

C. Standard Deviation Rate C.V of LQI

The LQI standard deviation can well reflect its own fluctuation degree, Reference [24] has pointed out that LQI mean can be used to evaluate the routing, but a lot of data packets are required to ensure accuracy. However, LQI standard deviation has been proved that can choose the communication paths quickly. Zhu Jian et al. proposed the link appraisal model based on Gaussian distribution, and discussed and proved that packet reception rate (PRR) related with the mean and standard deviation of LQI, and the experiments show that there was a good fitting relationship between PRR and LQI mean, the LQI standard deviation can well reflect the volatility of PRR [21].

We discovered that LQI mean can well indicate the link quality when it is in high or low levels. When LQI mean is in the transition interval, it cannot very good reflect link quality because the link quality has severe vibration. In order to remove the vibration, a new metric based on dynamic weight of LQI mean is proposed. According to statistical knowledge, the parameter called Coefficient of Variance (C.V) or standard deviation rate is introduced, as is shown in (1).

\[
CV = \frac{\sigma}{\mu} \tag{1}
\]

Where \( \sigma \) is the standard deviation of data, \( \mu \) is the average value of data, and C.V is discrete coefficient or variation coefficient. C.V represents the dispersion degree of data under the condition of different mean, and can reflect the impact of different LQI mean. The larger the C.V value is, the higher dispersion degree of LQI mean is, and the stability of link is worse.

III. LQIBM AND ITS APPLICATION

A. Construct LQIBM

According to the analysis of section II, we know that there is a high fitting degree between LQI mean and PRR, and the LQI mean can estimate the link quality of single-hop under various influence factors. However, it is easy to appear bottleneck link in multi-hop path, LQI mean is high in the path, and cannot completely represent that LQI mean of each link is high. So the parameter C.V is introduced, which can dynamically estimate the path quality by combining LQI mean with C.V values, and the selection probability \( P \) of routing is constructed, the proposed routing metric is called LQIBM, which can be expressed as (2).

\[
P = \alpha P_{cm} - (1 - \alpha)C.V \tag{2}
\]

Where \( C.V = \frac{\sigma}{\mu} \), C.V is variation coefficient of LQI, \( \mu \) is the average value of LQI in the entire path, namely, \( \mu = \frac{1}{n} \sum_{i=1}^{n} x_i \), \( \sigma \) is the standard deviation of LQI, namely, \( \sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \mu)^2} \).

The larger the C.V value is, the higher dispersion degree of LQI is, and the higher the possibility of bottleneck links is. So this value plays a negative role in the evaluation of paths.

\[
P_{cm} = e^{-\frac{\text{LQI mean}^2}{2(C.V)^2}}, \text{ it is probability of closing to the Max,}
\]

and the change of LQI is nonlinear, \( P_{cm} \) can be obtained by calculating and quantizing from the fitting curve between LQI mean and PRR. \( P_{cm} \) is a quantitative value that indicates the proximity degree of LQI mean with LQI maximum, and it can respond quickly to the PRR. The greater \( P_{cm} \) is, the larger PRR is, at the same time, the link quality is better and more reliable.

\( \alpha \) is the weight coefficient that determines weights of \( P_{cm} \) and \( C.V \) to selection probability, it is in the range of \([0,1]\). The larger \( \alpha \) is, and the greater LQI mean influence on selection probability is, but the smaller standard deviation rate influence on selection probability is, the fitting map of packet loss rate is shown in Figure 2(a), the fitting map of \( C.V \) and LQI mean is shown in Figure 2(b). With the aid of Figure 2, we will discuss how to determine the specific value of \( \alpha \).
factors take up the similar proportion, their coefficients are both defined as 0.5. This method is more absolute, some improved methods will be proposed in this paper. According to Figure 2, supposed that the relationship of \( \alpha, \sigma \) and \( \mu \) is considered by monotonic curve, we find some information by analyzing the statistical data in the experiment, when LQI mean is in the range of 90~100, \( \alpha \) and \( \sigma \) is well correlated, the link quality is higher and it changes quite smoothly, therefore, the relationship between \( \alpha \) and \( \sigma \) is assumed as an exponential function. Similarly, in the range of 70~90, supposed that \( \alpha \) and \( \mu \) have a linear relationship, according to some assumed functions, the relevant fitting curves are analyzed and obtained by MATLAB. By comparison, one of the functions can well comply with the law of data, so it is selected as the result.

The function is described as follows, which is a piecewise function.

\[
\alpha = \begin{cases} 
1 & 100 < \mu \leq 110, \quad 0 < \sigma \leq 5 \\
\mu^{0.95(\mu-5)} & 90 < \mu \leq 100, \quad 5 \leq \sigma \leq 20 \\
0.5e^{0.02(\mu-90)} & 80 < \mu \leq 90, \quad 16 \leq \sigma \leq 21 \\
0 & 50 \leq \mu \leq 80, \quad 17 \leq \sigma \leq 25 
\end{cases}
\]

(3)

It may clearly see that standard deviation fluctuations is larger when LQI mean is in the range of 100~110, while the link quality of the entire path is higher. Therefore, the smooth exponential curve is chosen, and the weight coefficient \( \alpha \) is at a higher level, \( \alpha \) is in the range of 0.67~1. But in the range of 70~90, PLR is less than 50%, although the change of \( \mu \) is relatively single, \( \mu \) is the main influence factor in the whole, so the linear function is chosen, the value \( 1 - \alpha \) is at a higher level.

### B. Application of LQIBM

Routing metric LQIBM can combine with any routing protocol to evaluate paths, no matter the protocol is table-driven or on-demand. In the initialization phase of network, a node sends a certain number of beacons to its neighbor nodes to obtain the LQI value that is used to estimate the link quality between the node and its neighbors, then, the same number of LQI will be obtained by the neighbor nodes. But LQI value has a certain degree of fluctuation. The LQI mean will be extracted from those beacons to get available link quality parameter. Here it is worth noting that when packet loss occurs, the obtained LQI value is 0. However, the minimum value of LQI is not 0 but 50 in CC2430, so the value should be changed to prevent measurement errors. In table-driven routing protocol, the LQI value is added into the routing table information; while in on-demand routing protocol, the LQI value is appended into the routing request frame (RREQ). Here, an example that LQIBM is used to evaluate paths is given. It is assumed that there are two paths from the source node S to the destination node D, as is shown in Figure 3. The two
paths have the same number of hops, but each link in each path has a different LQI. The two paths are evaluated by LQIBM and the results are shown in table 1.

![Figure 3 S→D data transmission paths](image)

**TABLE 1 ROUTING METRIC COMPUTATION EXAMPLE**

<table>
<thead>
<tr>
<th>Routing</th>
<th>LQI mean</th>
<th>Standard deviation</th>
<th>LQIBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing1</td>
<td>97.33</td>
<td>15.04</td>
<td>0.667</td>
</tr>
<tr>
<td>Routing2</td>
<td>96.67</td>
<td>4.16</td>
<td>0.872</td>
</tr>
</tbody>
</table>

It is shown in Figure 3 that the lowest LQI value is 80 in routing 1. According to the fitting curve between LQI mean and packet reception rate (PRR), we can see that PRR is about 0.69 when LQI value is 80. Consequently, the maximum PRR of routing 1 is only $1 \times 0.69 \times 1 = 0.69$, and the link that the value of LQI is 80 becomes the bottleneck link. In the meanwhile, the PRR of routing 2 reaches $0.98 \times 0.96 \times 0.9 = 0.85$. Therefore, the routing 2 should be chosen to ensure higher reliability.

If LQIBM is adopted, the routing 2 can also be found quickly. From the above analysis, LQIBM can prevent the appearance of bottleneck links, and ensure high reliability of data transmission. If LQIM is adopted, the routing 1 has a higher LQI mean, and is will taken as the communication path, a high packet loss rate will happen. Under the influence of standard deviation, LQIM will inevitably bring about the problem of misjudgment, while LQIBM can effectively reduce the appeared probability of the bottleneck link in the transmission.

**IV. THE EXPERIMENTS TEST AND PERFORMANCE ANALYSIS**

In the experiment, transmission power can be set at several stages in CC2430, where the default value is 0dBm is. The antenna of PCB is integrated into wireless transceiver module, and the power of all nodes adopts battery. The experiment includes sending nodes, receiving nodes and the base station. All the nodes are under the default power, and be placed indoor without obstacles. The distance between the sender and the receiver is kept invariable. In order to exclude packet loss or transmission errors caused by congestion, the speed of data transmission is set to 3packets/s. The receiver stores data packets and extracts corresponding LQI value. When the receiver receives a certain quantity of data packets, it will transmit these packets to the base station. Through the serial port, the data packets will be sent to the PC. Both the sender and receiver are fixed 20cm above the ground, and the base station is located in the corner of the room.

![Figure 4 LQIBM evaluation effect](image)

The improved AODV routing protocol is adopted to achieve multi-path data transmission in the experiment, and each path that is generated from the routing protocol is evaluated by combining with LQIBM or LQIM. Here, the value of PRR is used to estimate the reliability of each path. The number of packet loss will be recorded under various measurement parameters. After several repeated experiments, the processed results are shown in Figure 4 and 5.

![Figure 5 LQIM evaluation effect](image)

It is shown in Figure 5 that the number of packet loss decreases with the increase of assessed value when the routing is judged by LQIBM. The evaluation model LQIBM presents a single-value curve, and the phenomenon of misjudgment doesn’t appear. However, it is shown in Figure 5 that the evaluation model LQIM shows a non-single value curve, the packet loss doesn’t decrease monotonously with the increase of LQI mean, and the unreliable path will be chosen, which has a larger LQI mean but higher PRR. In other words, the bottleneck links will appear in the selected path that leads to unreliable transmission. Finally, it is concluded that the amended LQIBM can evaluate the path more accurately than the routing metric LQIM, and can achieve higher reliability for end-to-end data transmission.

In order to verify the validity of the routing metric LQIBM, the data transmission experiment is done by the CC2430. Data packets are sent from the source node S to the destination D, where several multi-hops paths exist. According to the current method, one path which has the highest LQI mean should be selected. Here, in order to
check the reliability of the chosen path, all the paths generated by AOMDV are used to transmit data and record the effect of each path. The PLR is defined as parameter for end-to-end transmission, which estimates the reliability of the path.

\[ P_{\text{lost}} = \frac{n_D - n_s}{n_s} \]  \hspace{1cm} (4)

We can compare the reliability of each path through PLR. The results are listed in different tables according to various ranges of LQI mean, and it is shown in table2-4.

It is shown in table 2 that the link quality has a good stability and small fluctuations when LQI mean is in the range of 100–110, and the packet loss rarely happen, so LQI mean is only considered to evaluate paths, that is to say, the path with largest LQI mean will be chosen. Thus, the routing that the highest LQI mean is 106.37 and the lowest PLR is 0% is elected.

<table>
<thead>
<tr>
<th>TABLE 2</th>
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<tbody>
<tr>
<td>LQI MEAN IN THE RANG OF 100–110</td>
</tr>
<tr>
<td>Routing1</td>
</tr>
<tr>
<td>Link1</td>
</tr>
<tr>
<td>Link2</td>
</tr>
<tr>
<td>Link3</td>
</tr>
<tr>
<td>LQI mean</td>
</tr>
<tr>
<td>P</td>
</tr>
<tr>
<td>Packet loss rate</td>
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</table>

<table>
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<th>TABLE 3</th>
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<tbody>
<tr>
<td>LQI MEAN IN THE RANG OF 90–100</td>
</tr>
<tr>
<td>Routing1</td>
</tr>
<tr>
<td>Link1</td>
</tr>
<tr>
<td>Link2</td>
</tr>
<tr>
<td>Link3</td>
</tr>
<tr>
<td>LQI mean</td>
</tr>
<tr>
<td>Standard deviation</td>
</tr>
<tr>
<td>P</td>
</tr>
<tr>
<td>Packet loss rate</td>
</tr>
</tbody>
</table>

When LQI mean is in the range of 70–90, the link quality of majority paths is poor, and the bottleneck link appears easily. In such condition, through LQIBM, the paths still can be found, which has better link quality and no bottleneck link. The higher reliability will be achieved in such a poor condition. It is shown in table 4 that routing 3 has the largest LQI mean, but the PLR is the highest, and shouldn’t be selected. So routing 1 is chosen, and a transmission reliability of 85% is achieved. In the range of 70–90, the standard deviation is quite high, so LQI mean is used to define the weight coefficient \( \alpha \). This experiment selects the special case (standard deviation is in lower status) to prove the validity of selection probability. The results show that the weighted formula can be well applied to make a distinction of the bottleneck link. LQIBM has the applicability and reliability when the LQI value is in a tough situation, no matter the LQI standard deviation is high or low.

From the evaluation results in the tables above, it is concluded that routing metric LQIBM divides the path quality into several clear levels, and that makes the assessment of paths more accurate, and can ensure higher reliability of data transmission. When the path quality is not so satisfactory, the metric can effectively find a superior path which has high quality and stable performance. The routing metric LQIBM successfully avoids the appearance of the bottleneck links, and enhances the reliability of the data transmission.

<table>
<thead>
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<th>TABLE 4</th>
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<tbody>
<tr>
<td>LQI MEAN IN THE RANG OF 70–90</td>
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<tr>
<td>Routing1</td>
</tr>
<tr>
<td>Link1</td>
</tr>
<tr>
<td>Link2</td>
</tr>
<tr>
<td>Link3</td>
</tr>
<tr>
<td>LQI mean</td>
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<tr>
<td>Standard deviation</td>
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<tr>
<td>P</td>
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<tr>
<td>Packet loss rate</td>
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</tbody>
</table>

It is shown in table 3 that the bottleneck links are link 1 in routing 1, and are link 3 in routing 2. When the LQI mean is in the range of 90–100, if only the LQI mean is considered to estimate the routing, and the routing 1 will be chosen because it has the highest LQI mean. However, the experiment results show that the reliability in routing 1 reaches only 93% because of the bottleneck link. In fact, through the improved routing metric LQIBM, the model has revised the selection bias due to the bottleneck. It is successful to select routing 3 to transmit data, and the PRR get to 98%.

V. CONCLUSIONS

The paper presents a novel method LQIBM, which dynamically combines LQI mean with Coefficient of Variance (C.V) to evaluate communication paths. The routing metric LQIBM selects the path which has high link quality and stable performance of transmission. This article verifies that LQI mean can effectively estimate link quality under the various influence factors. The new metric can effectively exclude the bottleneck link. In this way, data transmission can achieve a higher reliability by using the proposed metric. Furthermore, this routing metric will not lead to low quality data transmission due to misjudgment.
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REFERENCE


Rongbiao Zhang male, doctor, Professor and doctoral tutor, was born in Haimen city, Jiangsu Province in 1957. Now he is control theory and control engineering doctoral subject leader of Jiangsu University, deputy director of the Institute of automation. He is mainly engaged in wireless sensor network and automatic detection technology, intelligent instrument and information processing technology, fault diagnosis and system reliability and other aspects of the research work.

Yongxian Song was born in Xuzhou, on April 1,1975. He received the B.S. degree in Applied Electronic Technology from Huaihai Institute of Technology, Lianyungang,China, in 1997, and the M.S. degree in Control Theory and Control Engineering from Jiangsu university, Zhenjiang, China , in 2006. From 2009 to now, He is studying for Ph.D degree in Control Theory and Control Engineering from Jiangsu university, Zhenjiang, China.

Since 2006, he has been a teacher in Huaihai Institute of Technology, Lianyungang,China. His current research interests include signal processing ,intelligent control, and industrial control.