



## **ZIGBEE TRANSMISSION POWER DYNAMIC ADJUSTMENT SYSTEM BASED ON FUZZY CONTROL**

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*Abstract-We designed a fuzzy controller for ZigBee equipment's transmission power adaptive adjustment. The controller is based on RSSI (Received Signal Strength Indicator). It can make a dynamic adjustment on the transmitted power according to the fuzzy control rules. The fuzzy control is suitable to solve the problem which is difficult to deal with in building system mathematical model. What's more, the fuzzy control system has perfect performance in response speed and antijamming capability. It's convenient to embed in devices. In this paper we use Ti Company's CC2530 chip as an experiment object. By using the fuzzy controller we keep the transmission power to the minimum. By this way, the energy consumption can be reduced on the premise of ensuring normal communication. The fuzzy controller system has a good steady-state and dynamic performance, and contributes to the ZigBee system's stability and low power consumption performance.*

**Index terms:** fuzzy control, ZigBee, RSS, CC2530, low power consumption

## I. INTRODUCTION

ZigBee is a low power personal area network (PAN) protocol based on the IEEE 802.15.4 standard. The technology according to this technical agreement is a wireless communication technology of low power consumption. It has features such as short distance, low complexity, self-organization, low power consumption, low transfer rate and low cost [1-3]. It can be embedded into a variety of devices and suitable for automatic control, remote control, environmental monitoring and other fields [4].

ZigBee devices have three work modes called transmit, receive and sleep. Generally, the ZigBee device will enter into the sleep mode during its free time to meet the purpose of reducing consumption [5]. The transmit mode has the largest power consumption. In order to ensure the transmission quality the ZigBee protocol using the maximum power as default sets. But for nodes with small distance, using small transmission power is enough to ensure good communication quality. So we can control the transmission power and keep it to the minimum transmission power which can ensure normal communication. By using this system, we can get less power consumption [6].

Most of researches on this subject are to make a set according to distance or the RSSI's statistic at the network organization time. These strategies can achieve good performance on condition that the distribution of the nodes is invariable. However, in case that the node is moved or network topology is changed during the network is running, the network won't adjust the transmission power immediately. In these cases, the performance of the nodes will go down and unexpected network off-line maybe occurred for worse [7] [8]. Some researches implement the dynamic adjustment of power by running an algorithm on the ZigBee devices which need to be adjusted. In consideration of ZigBee devices' limited computing resources and difficult to establish accurate mathematics model, these methods need to solve two key problems. One is that how to keep the balance between algorithm performance and computing resource consumption. The other is that how to establish or avoid establishing accurate mathematics model [9] [10].

This paper uses the fuzzy control algorithm, so we do not need to establish accurate mathematical model. By building a fuzzy controller and using the controller I/O table, the ZigBee devices can avoid the huge computational cost which has been done during the fuzzy controller's design time.

## II. COMPOSITION OF TRANSMISSION POWER CONTROL SYSTEM

A typical ZigBee network topology is shown in figure 1[4]. To ensure maximum network coverage, the network's Coordinator and Router's transmission power has been set to +4.5dB which is the maximum value (The value may have differences due to different chips and antennas, the +4.5dB is for CC2530)

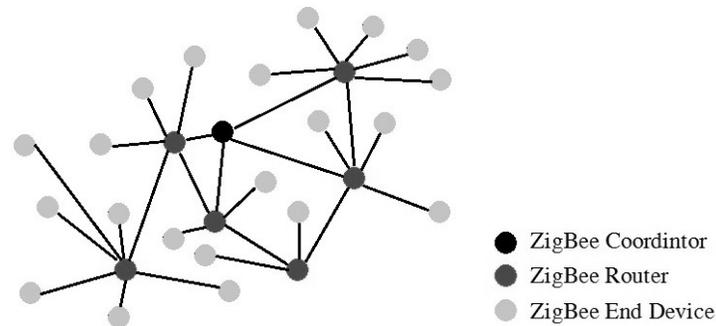


Figure 1. A typical mesh network

The control system is used to regulate the End Device's transmission power to keep it as small as possible on the premise of ensuring normal communication. In other words, we must keep the End Device's signal strength similar to the receiving sensitivity's, when its signal arrives at the receiver (The upper Router).

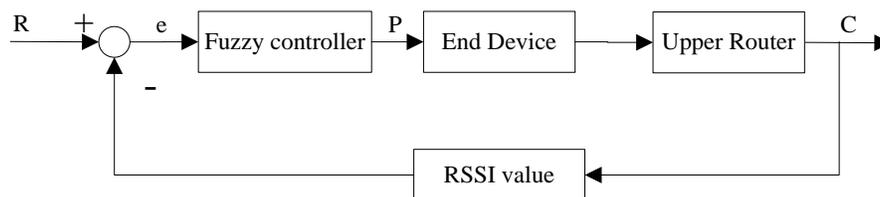


Figure 2. The control system structure diagram

The control system structure is shown in figure 2[12].

The legend: The  $C$  is the received signal strength that comes back from its upper Router.  $C$ 's value (It is the actual RSSI value) is the control system's negative feedback input;

The  $R$  is the given RSSI value which is the RSSI value corresponding to the receiver sensitivity.

To ensure the communication quality,  $R$  is the RSSI value corresponding to the maximum

sensitivity. For chip CC2530, the receiving sensitivity characteristic value is -97 dB and the maximum sensitivity value is -88 dB. So  $R$  is -88dB;

The  $e$  is the deviation between the actual RSSI value and the given RSSI value  $R$ ;

The  $P$  is the transmission power value that has been calculated and ready to take effect. The  $P$  is used to control the End Devices' transmission power. The End Devices make the  $P$  to take effect by calling interface function `macRadioSetTxPower( uint8 txPower )` [4].

In the system, we can reach the target of keeping the End Device's signal strength similar to given RSSI value  $R$  by building an appropriate fuzzy controller.

### III. DESIGN OF FUZZY CONTROLLER

#### a. Description of Fuzzy Control Strategy

As the End Devices' link conditions are different and their distances to Router are also different, the RSSI values of different signals received by Router are different from each other [9].

The specific control strategy is as follows. The condition in which RSSI value is greater than  $R$  ( $e$  is a negative number) indicates that the End Device's signal strength is strong and we can reduce the transmission power appropriately. The condition in which RSSI value is smaller than  $R$  ( $e$  is a positive number) indicates that the End Device's signal strength is weak and we can increase the transmission power appropriately. Meanwhile, on condition that  $e$  is a negative number, the smaller the  $e$  is, the larger the decreasing amplitude of the transmission power is. On condition that  $e$  is a positive number, the bigger the  $e$  is, the larger the increasing amplitude of the transmission power is [11].

#### b. Composition of the Fuzzy Controller

The controller's output is the transmission power value which is ready to take effect. The output of the controller is determined by the given RSSI value, the actual RSSI value and the current transmission power. The three variables are marked with  $u_0$ ,  $u_1$  and  $u$ . The controller's output is marked with  $y$ . They have function relation  $y = f(u, (u_0 - u_1))$ .

The function  $f(u, (u_0 - u_1))$  has described a two-dimensional fuzzy controller with input variables  $u$  and  $(u_0 - u_1)$ . The variable  $u_0$  is shown as  $R$  in figure 2, and  $u_0 = -88dB$ . The variable  $(u_0 - u_1)$  is shown as  $e$  in figure 2. Then, the calculated transmission power value  $y = f(u, e)$  is shown as  $P$  in figure 2. The fuzzy controller structure is shown in figure 3.

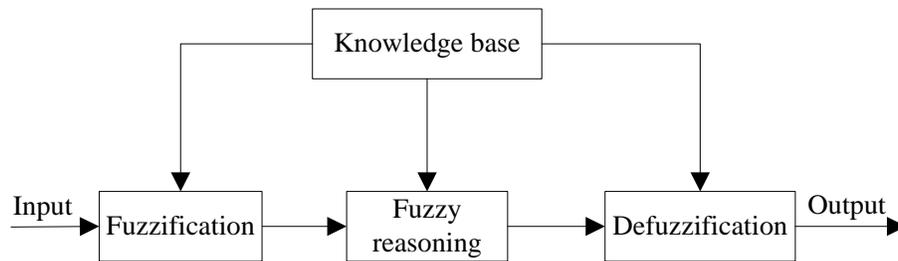


Figure 3. The fuzzy controller structure diagram

The current transmission power  $u$  can be acquired by reading register value from the signal transmission power register. The corresponding relation between register values and the actual transmission power is shown as table 1.

Table 1. The lookup table of the actual transmission power from transmission power registers value

| Register value | Actual transmission power (dB) | Current(mA) |
|----------------|--------------------------------|-------------|
| 0xF5           | 4.5                            | 34          |
| 0xE5           | 2.5                            | 31          |
| 0xD5           | 1                              | 29          |
| 0xC5           | -0.5                           | 28          |
| 0xB5           | -1.5                           | 27          |
| 0xA5           | -3                             | 27          |
| 0x95           | -4                             | 26          |
| 0x85           | -6                             | 26          |
| 0x75           | -8                             | 25          |
| 0x65           | -10                            | 25          |
| 0x55           | -12                            | 25          |
| 0x45           | -14                            | 25          |
| 0x35           | -16                            | 25          |
| 0x25           | -18                            | 24          |
| 0x15           | -20                            | 24          |
| 0x05           | -22                            | 23          |

The controller’s working process is as follows. First the fuzzy controller executes fuzzification process of the input variables  $u$  and  $e$ . Then, the controller will calculate fuzzy output variable in accordance with the fuzzy rules in the knowledge base. Finally, the fuzzy controller executes defuzzification process of the fuzzy output variable to get accurate output variable  $y$ . After that, the  $y$  will be set as the transmission power.

c. Fuzzification Process

After experiment, we got that  $u_1 \in [-101, -41]$  for ZigBee Device with CC2530 core. So, there is  $e \in [-47, 13]$  as  $e = (u_0 - u_1)$ . After the linear transformation for  $e$ , we got the universe of discourse  $E = [-6, 2]$  follow the transformation formula (1). Similar to  $e$ , it signed the  $U$  as the universe of discourse of the input variable  $u$ . Then  $U = [-2, 6]$  follow the transformation formula (2). The universe of discourse of  $y$  is similar to  $u$ ’s and it is signed with  $Y$ .

$$x_1' = -2 + (x_1 + 17) / 7.5 \tag{1}$$

$$x_2' = 2 + (x_2 + 8.75) / 3.31 \tag{2}$$

Five fuzzy subsets were defined in  $U$  and  $Y$ . They are {*Weak, Middle, Strong, Very Strong, Extremely Strong*} and signed with { $W, M, S, VS, ES$ }. Other Five fuzzy subsets were defined in  $E$ . They are {*Negative Big, Negative Middle, Negative Small, Zero, Positive Small*} and signed with { $NB, NM, NS, ZO, PS$ }. They are shown in Table 2.

Table 2. Definition of the fuzzy variables

| Variables | Universe of discourse | Fuzzy subsets            |
|-----------|-----------------------|--------------------------|
| $e$       | $E = [-6, 2]$         | { $NB, NM, NS, ZO, PS$ } |
| $u$       | $U = [-2, 6]$         | { $W, M, S, VS, ES$ }    |
| $y$       | $Y = [-2, 6]$         | { $W, M, S, VS, ES$ }    |

The fuzzy controller can get the smooth output (System gain high stability) in the condition of fuzzy subsets’ membership functions is fit for the gauss curve. As the embedded CPU has limited computing ability, we have simplified the function. According to the test data, the membership functions of input and output variables can adopt the triangular function. This function can

regulate efficiency and stability's compromise, and then reach the design target. The Figure 4 is the membership function of  $u$  and  $y$ .

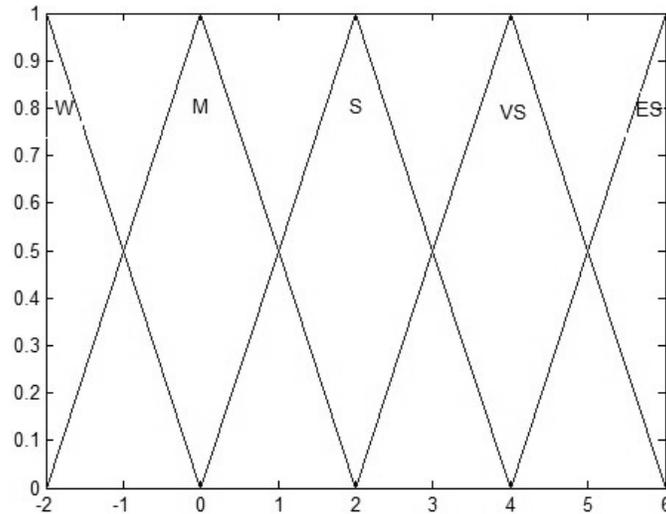


Figure 4. Membership functions of  $u$  and  $y$

d. Fuzzy Reasoning and Defuzzification

Firstly, make the fuzzy rules. According to the results of experiment and control engineering knowledge, we got fuzzy rules as follow. As shown in Table 3, the stronger the actual signal is, the bigger the power reduction (on the basis of the current transmission power) amplitude is. The weaker the actual signal is, the bigger the power increase (on the basis of the current transmission power) amplitude is.

Table 3. Fuzzy rule table

| $E_i, Y_i$<br>$U_i$ | <i>PS</i> | <i>ZO</i> | <i>NS</i> | <i>NM</i> | <i>NB</i> |
|---------------------|-----------|-----------|-----------|-----------|-----------|
| <i>W</i>            | <i>M</i>  | <i>W</i>  | <i>W</i>  | <i>W</i>  | <i>W</i>  |
| <i>M</i>            | <i>S</i>  | <i>M</i>  | <i>W</i>  | <i>W</i>  | <i>W</i>  |
| <i>S</i>            | <i>VS</i> | <i>S</i>  | <i>M</i>  | <i>W</i>  | <i>W</i>  |
| <i>VS</i>           | <i>ES</i> | <i>VS</i> | <i>S</i>  | <i>M</i>  | <i>W</i>  |
| <i>ES</i>           | <i>ES</i> | <i>ES</i> | <i>VS</i> | <i>S</i>  | <i>M</i>  |

The above fuzzy rules can be summarized as:

$$\text{if } (E_i \text{ and } U_i) \text{ then } Y_i \quad (3)$$

The corresponding fuzzy implication relation matrix is:

$$R = E_i \times U_i \times Y_i \quad (4)$$

The fuzzy reasoning:

$$Y_i = E_i \times U_i \circ R \quad (5)$$

Target output value:

$$y = 3.31(y^* - 4.64) \quad (6)$$

In the above formulas,  $Y_i$  is a fuzzy subset and the actual output value  $y$  is an exact value. To ensure real-time performance, it adopts maximum membership degree method to make defuzzification of  $Y_i$ . Sign the output value after the defuzzification with  $y^*$ , we can get  $y$  by inverse scale transform formula (6) [13] [14].

Considering the embedded system's limited resources of storage space and computing, we use look-up table method. According to the above algorithm and with help of MATLAB, we can beforehand generate control system I/O table on PC. The part control system I/O table is shown in Table 4. If the sampling interval of  $u_1$  and  $u$  is 2 and output result  $y$  takes 1 decimal places. Then, the storage space of the whole table is about 1KB. It has little impact on controller performance.

Table 4. Control system I/O table (dB)

| $u_1$<br>$y$<br>$u$ | -101  | -99   | -97   | -95   | -93   | -91   |
|---------------------|-------|-------|-------|-------|-------|-------|
| -22                 | -15.4 | -15.4 | -15.4 | -15.4 | -18.9 | -19.8 |
| -20                 | -15.4 | -15.4 | -15.4 | -15.4 | -18.9 | -19.8 |
| -18                 | -11.4 | -11.4 | -11.4 | -11.4 | -15.4 | -15.4 |
| -16                 | -9.4  | -9.6  | -10.5 | -11.4 | -15.4 | -15.4 |
| -14                 | -10.1 | -10.1 | -10.5 | -11.4 | -15.4 | -15.4 |
| -12                 | -8.6  | -8.6  | -8.6  | -8.6  | -12.0 | -12.0 |
| -10                 | -4.6  | -4.6  | -5.6  | -7.4  | -11.8 | -10.9 |

During the system running, every time it gathers values of the input variables  $u_1$  and  $u$ , searches the control system I/O table to find out the correspondence or similar input values. Then, the system can get the output value in the table. After setting the value as output power, the system will finish one adjustment period.

#### IV. EXPERIMENT RESULTS AND ANALYSIS

##### a. Experiment environment

The hardware system adopts TI Company's chip CC2530 as the core. The whole network consists of a coordinator, two routers (1, 2), and 15 end-nodes (from 6 to 20), you can choose any one of the end-node as the experiment object.

Experimental methods: under the open environment, constantly increase the distance between the measured node and its upper router, respectively record changes of the system when the transmission power of the end-node is the maximum, minimum, under relay control strategy (adjusted by fixed change of 2 dB) and fuzzy adjusted, namely record changes of the signal strength that on arrival at the router, the transmission power setting value of the end-node and the current consumption value. At a certain moment during the normal running of the system, we cover the End Device (It simulates strong interference appear) and uncover the End Device (It simulates strong interference disappears). Then, we observe the dynamic characteristics of control system via the recorded process and change times that the system changes to the steady state.

##### b. Experiment Results

As shown in table 5, under the minimum transmission power, they are changes of the signal strength  $C$  that on arrival at the router at the distance  $D$ , respectively, 1m, 3m, 5m, 8m, 10m, 15m, 20m. The transmission power value  $P$  is constant for -22dB and power consumption value  $I$  is constant for 23mA.

Table 5. Signal power changes under the minimum transmission power

|              |     |     |     |     |     |     |     |
|--------------|-----|-----|-----|-----|-----|-----|-----|
| <b>D(m)</b>  | 1   | 3   | 5   | 8   | 10  | 15  | 20  |
| <b>C(dB)</b> | -77 | -81 | -87 | -89 | -90 | -96 | -98 |

As shown in table 6, under the maximum transmission power, they are changes of the signal strength C that on arrival at the router at the distance D, respectively, 1m, 5m, 10m, 20m, 30m, 40m, 50m, 60m, 70m. The transmission power value P is constant for 4.5dB and power consumption value I is constant for 34mA.

Table 6. Signal power changes under the maximum transmission power

|              |     |     |     |     |     |     |     |     |     |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| <b>D(m)</b>  | 1   | 5   | 10  | 20  | 30  | 40  | 50  | 60  | 70  |
| <b>C(dB)</b> | -58 | -60 | -68 | -70 | -73 | -77 | -79 | -83 | -87 |

As shown in table 7, under the control of fuzzy control system, they are changes of the signal strength C, the transmission power value P and power consumption value I that on arrival at the router at the distance D, respectively, 1m, 5m, 10m, 20m, 30m, 40m, 50m, 60m, 70m.

Table 7. Signal power changes under the transmission power fuzzy control

|               |     |     |     |      |     |     |      |     |     |
|---------------|-----|-----|-----|------|-----|-----|------|-----|-----|
| <b>D(m)</b>   | 1   | 5   | 10  | 20   | 30  | 40  | 50   | 60  | 70  |
| <b>C(dB)</b>  | -75 | -87 | -86 | -86  | -90 | -85 | -84  | -82 | -89 |
| <b>P (dB)</b> | -22 | -22 | -14 | -1.5 | -7  | -6  | -1.5 | -3  | 4.5 |
| <b>I(mA)</b>  | 23  | 23  | 25  | 27   | 26  | 26  | 27   | 27  | 34  |

As shown in table 8, under the control of fuzzy control system, they are the changes of the signal strength C during 14 times of adjustment when interference suddenly appears and disappears. The C+ is for interference appeared and C- is for the interference disappeared (The changes of the interference are take place between the first and second time of adjustment).

Table 8. The dynamic response of fuzzy control system

|                        |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| <b>Times of Adjust</b> | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  |
| <b>C+(dB)</b>          | -74 | -98 | -99 | -90 | -88 | -92 | -88 | -86 | -86 | -88 | -85 | -89 | -87 | -86 |
| <b>C-(dB)</b>          | -86 | -63 | -77 | -73 | -73 | -74 | -76 | -77 | -76 | -74 | -74 | -76 | -74 | -75 |

### c. Analysis of experiment results

This paper draws the data in a table into curved forms, in order to facilitate data analysis.

Drawing a curve based on data in table 7, making the distance of sending and receiving for horizontal axis, and the signal power for the vertical axis, we can get a curved form as shown in figure 5. From the figure we can see that, with increasing the distance of sending and receiving, the transmission power of ZigBee end-node being measured increases gradually, making the signal strength on arrival at the upper router stable around the given value.

Figure 6 shows the system performance using the relay control strategy. Comparing with Figure 5, it can be seen that the terminal signal intensity scanned by upper router changes more gradual under control of the fuzzy control strategy. It indicating that under the control of fuzzy control strategy the system has achieved a better stability.

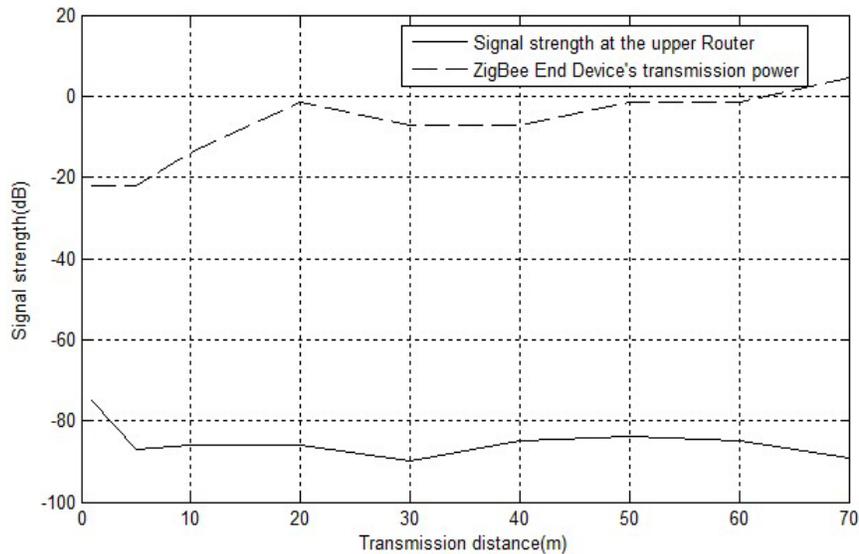


Figure 5. Fuzzy control system performance

Drawing a curve based on data of the signal strength C at the upper router in table 5, table 6, table 7, making the distance of sending and receiving for horizontal axis, and the signal power for vertical axis, we can get a curved form as shown in figure 7.

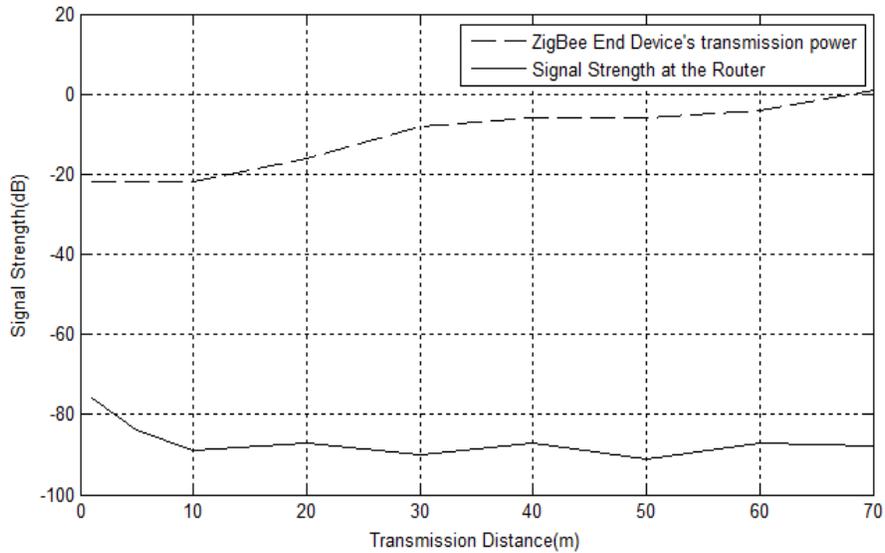


Figure 6. Delay control strategy system performance

From the figure we can see that, with increasing the distance of sending and receiving (or the distance is constant, interference or obstruction is gradually increased), and under the maximum transmission power, the signal strength C at the upper router is greater than the given value within the distance from 1m to 70m, so it exists energy waste; Under the minimum transmission power, the signal strength C at the upper router is less than the given value when the distance is more than 10m, so the quality of communication will be affected; Using fuzzy control system to control the transmission power, the signal strength C is approximate to the situation of the minimum transmission power within the 1 to 10m, its signal strength is stably around the given value, namely the minimum transmission power ensuring the quality of communication.

Drawing a curve based on data of the current consumption values in table 2, table 3, table 4, making the distance of sending and receiving for horizontal axis, and the current consumption for vertical axis, we can get a curved form as shown in figure 8. From the figure we can see that, with the distance increasing from 1m to 70m, and under the maximum transmission power, the current always maintained at 34mA; under the minimum transmission power, it always maintained at 23mA; under using fuzzy control system to control the transmission power, the current is gradually increased from 23mA to 34mA. On the assumption that the end-node moves from 0 to 70m at a constant speed, then from the figure 8 we can estimated that, compared with those with the maximum transmission power, energy saving rate using the automatic adjustment system is about 20%.

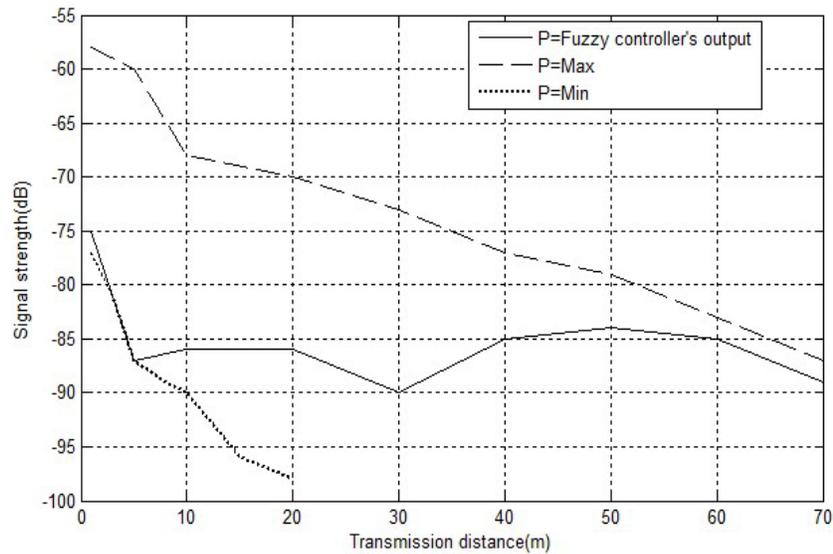


Figure 7. Signal power attenuation curve

Drawing a curve based on the data of the signal strength C in table 8, making the number of adjust for horizontal axis, and the signal strength for vertical axis, we can get a curved form as shown in figure 9. From the figure we can see that, when the interference appeared, the power of signal at the upper Router sharply decreased and returned to the stable state after adjusting twice. When the interference disappeared, the power of signal at the upper Router sharply increased and returned to as the stable state after adjusting once.

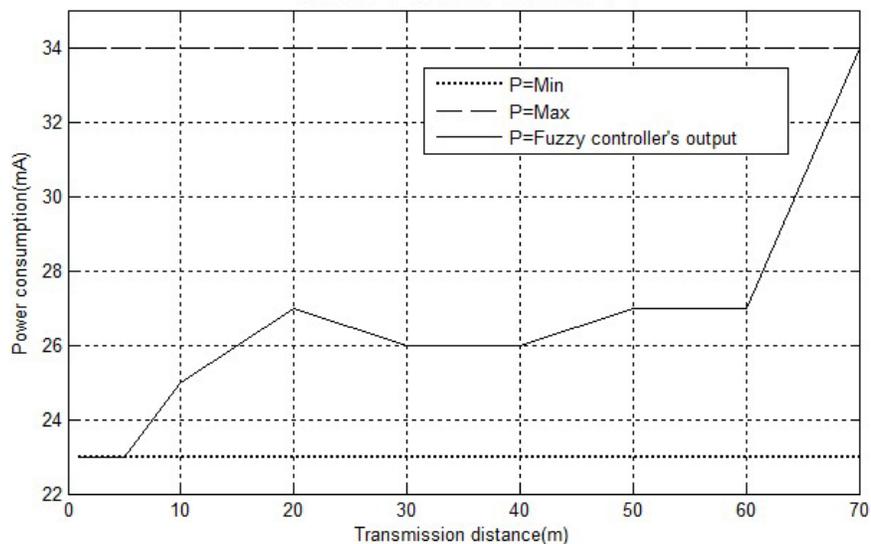


Figure 8. Current consumption curve

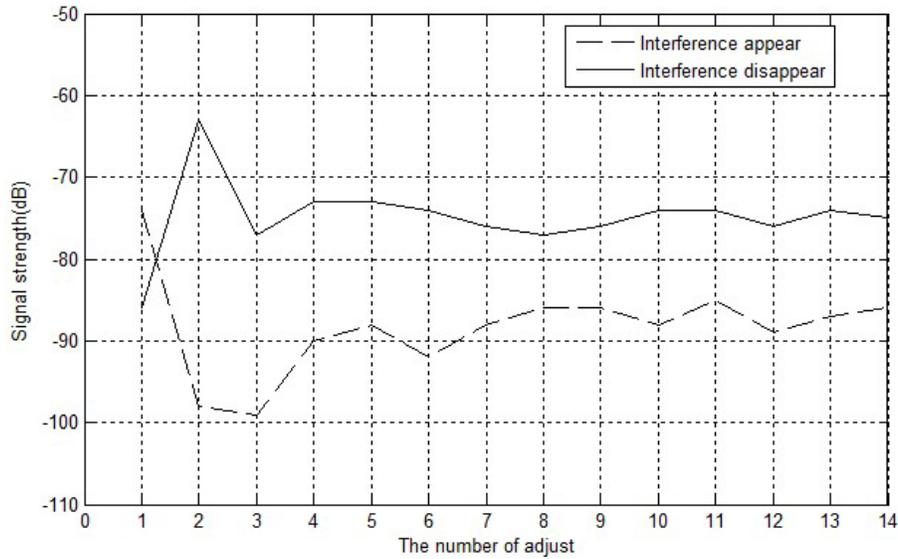


Figure 9. Dynamic response curve under fuzzy control strategy

As shown in figure 10, when the interference appeared, the power of signal at the upper Router returned to the stable state after adjusting 4 times. When the interference disappeared, the power of signal at the upper Router returned to the stable state after adjusting 4 times, too. Through compared with figure 9, it can be seen that under the fuzzy control strategy, the system can return to stable state more quickly after interference appear and disappear. That is the fuzzy control strategy has better dynamic performance than the relay control strategy in ZigBee terminal transmission power adjustment.

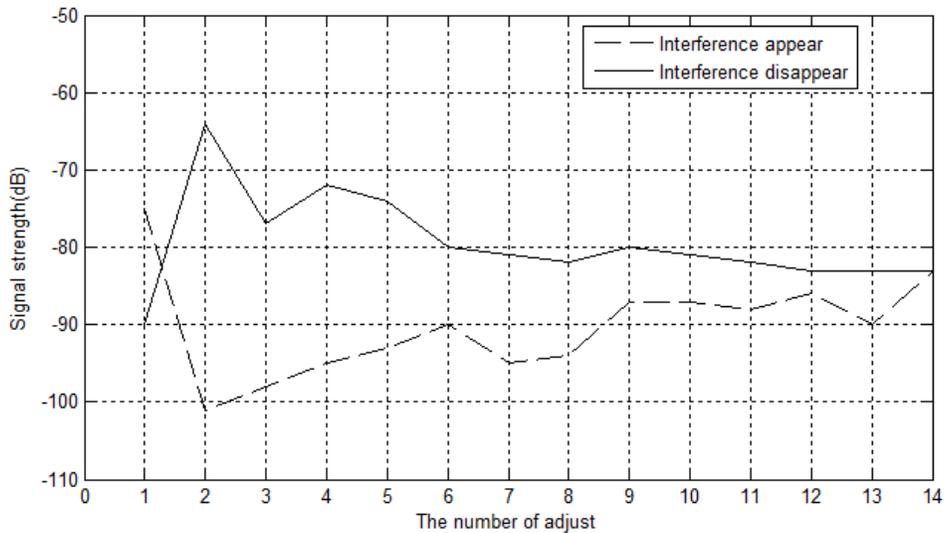


Figure 10. Dynamic response curve under relay control strategy

## V. CONCLUSIONS

The method proposed by the paper is only used to adjust the transmission power of terminal nodes, so it can be applied in the network types as point to point type, star type and mesh type network, with the same adjusting method.

The reasons that only adjusting the transmission power of terminal nodes are as follows:

- (1) Most nodes in one network are terminal nodes.
- (2) To ensure maximum network coverage, coordinator and routing use maximum transmission power.

Through the above analysis it can be seen that using fuzzy control method to adjust ZigBee Device's transmission power can deeply reduce the power consumption of the system and improve the system stability. Most of all it has a good dynamic performance on condition that network changes or node moved.

## VI. ACKNOWLEDGE

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## REFERENCES

- [1] J.H.Yang, D.L.Xu and X.L.Wang, "Research and Application of Campus Power Equipment Monitoring System Based on ZigBee", *Automation & Instrumentation*, No. 12, 2011, pp. 29-32.
- [2] P.Yu, "ZigBee-A Wireless Communication Protocol with Features of Low Power, Low Cost, High Reliability and Low Complexity", *Automation & Instrumentation*, Vol. 26, No. 5, 2005, pp .1-4.
- [3] Texas Instruments Incorporated, CC253x System-on-Chip Solution for 2.4-GHz IEEE 802.15.4 and ZigBee® Applications. USA: Texas Instruments Incorporated, 2012.
- [4] Texas Instruments Incorporated, Z-Stack Developer's Guide, USA: Texas Instruments Incorporated, 2011.
- [5] Y.Tang, M.T.Zhou and X. Zhang, "The reviewed of wireless sensor network routing protocol", *Journal of Software*, Vol. 17 No. 3, 2006, pp. 412-417.

- [6] Y.L.Liu, J.H.Pu, W.W.Fang and Z.Xiong, "An optimization algorithm of wireless sensor network MAC protocol", Chinese Journal of Computers, Vol. 35 No. 3, 2012, pp. 530-536.
- [7] Sean Dieter Tebje Kelly, Nagender Kumar Suryadevara, and S. C. Mukhopadhyay, "Towards the Implementation of IoT for Environmental Condition Monitoring in Homes" IEEE SENSORS JOURNAL, VOL. 13, NO. 10, OCTOBER 2013, pp. 3846-3853.
- [8] Y.W Zhou, Z.H.Ling and Q.Q.Wu, "The discussed of ZigBee wireless communication technology and its application", Automation & Instrumentation, Vol. 26, No. 6, 2005, pp. 5-9.
- [9] J.F. Wang, "Wireless sensor network based on the ZigBee", Sandong: Jinan University, 2010.
- [10] M.K. Fang and L.Li, "An adaptive transmission power control scheme for WLAN", Computer Engineering, Vol. 38, No. 13, 2012, pp. 86-88.
- [11] N.K. Suryadevara, S.C. Mukhopadhyay, R. Wang, R.K. Rayudu, Forecasting the behavior of an elderly using wireless sensors data in a smart home, Engineering Applications of Artificial Intelligence, Volume 26, Issue 10, November 2013, Pages 2641-2652, ISSN 0952-1976, <http://dx.doi.org/10.1016/j.engappai.2013.08.004>.
- [12] Y.Feng, X.Z.Zhou and B. Li. "The optimization method of transmission power based on CC2430", Microcomputer Information, Vol. 25 No. 11, pp. 40-41, 2009.
- [13] K. Kaur, S. C. Mukhopadhyay, J. Schnepper, M. Haefke and H. Ewald, "A Zigbee Based Wearable Physiological Parameters Monitoring System", IEEE Sensors Journal, Vol. 12, No. 3, March 2012, pp.423-430.
- [14] Y.S. Ding and L.H.Ren, "A novel fuzzy self-tuning immune feedback control system", Control and Decision, Vol. 25 No. 11, 2000, pp. 443-446.
- [15] N. K. Suryadevara and S. C. Mukhopadhyay, "Determining Wellness Through An Ambient Assisted Living Environment", IEEE Intelligent Systems, May/June 2014, pp. 30-37.
- [16] J.M.Shi, J.Wang and S.W.Liu, "Fuzzy adaptive time-varying time-delay uncertain systems'  $H_\infty$  control", Systems Engineering and Electronics, Vol.34, No. 3, 2012, pp. 550-553.
- [17] M. Haefke, S. C. Mukhopadhyay and H. Ewald, A Zigbee Based Smart Sensing Platform for Monitoring Environmental Parameters, Proceedings of IEEE I2MTC 2011 conference, IEEE Catalog number CFP11MT-CDR, ISBN 978-1-4244-7934-4, May 10-12, 2011, Hangzhou China, pp. 1549-1556.

[18] H.B. Zhou, H. Ying and J.A. Duan, “Adaptive control using interval Type-2 fuzzy logic for uncertain nonlinear systems”, *Journal of Central South University of Technology*, Vol.18 No. 3, 2011, pp. 60-766.

[19] M. Haefke, S. C. Mukhopadhyay and H. Ewald, A Zigbee Based Smart Sensing Platform for Monitoring Environmental Parameters, *Proceedings of IEEE I2MTC 2011 conference*, IEEE Catalog number CFP11MT-CDR, ISBN 978-1-4244-7934-4, May 10-12, 2011, Hangzhou China, pp. 1549-1556.

[20] Y.N.Yang, J. Wu and W. Zheng, “Adaptive fuzzy sliding mode control for robotic airship with model uncertainty and external disturbance”, *Journal of Systems Engineering and Electronics*, Vol.23, No. 2, 2012, pp. 250-25.