A Novel Fuzzy Algorithm for Power Control of Wireless Sensor Nodes

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Abstract—In wireless sensor network, it is essential to find effective means for power control of randomly distributed nodes. In this paper, based on diverse receiving QoS parameters, a fuzzy algorithm for peer to peer power control of wireless sensor nodes is proposed. Simulation results show that the proposed algorithm reduces packet error rate (PER) and prolongs survival time of network, compared with fixed transmission power method. Thus, this fuzzy algorithm could realize reliable data transmission with low power consumption.

Index Terms—fuzzy algorithm; power control; peer to peer; receiving QoS.

I. INTRODUCTION

Wireless sensor nodes are resource-constrained[1] which makes it essential for these sensor nodes to conserve energy to increase lifetime of the sensor network.

On the issue of power control in wireless sensor network (WSN), most designs have focused on cluster head selection. To form an energy efficient network, G.S.Tomar[2] et al proposed a dynamic multi-level hierarchal clustering approach. Shangping Dai[3] et al presented an ACE-CILP clustering formation algorithm according to considering the energy consumption. Inbo Sim[4] et al proposed a CH selection algorithm. Proper cluster head really brings energy saving. However, after clustering formation, they paid no attention to energy efficient method on peer to peer communication, for example, the communication between sensor node and cluster head. In most cases, sensor nodes send packets to others with fixed power, which brings potential problems. Transmitting with a high power level causes interference and energy waste. While transmitting with a low power level causes packets loss. All the work mentioned above couldnt decide a proper transmission power for sending node. Due to it, maybe an adaptive power control algorithm for peer to peer is needed in WSN.

Fuzzy logic is a math theory newly used in WSN. To lower power consume, most researches based on fuzzy logic focus on new cluster head decision systems, effective MAC layer protocols and novel energy efficient routing protocols, respectively. In order to select cluster head and form an energy efficient network, Junpei Anno[5] et al proposed a power reduction cluster head decision algorithm for sensor networks based on fuzzy logic, and the parameters of fuzzy logic are number of neighbor nodes. Indranil Gupta[6] et al presented a fuzzy logic approach of cluster head election based on three descriptors C energy, concentration and centrality. Chih-Min Chao[7] et al proposed a fuzzy control quorum-based energy conserving protocol (FQEC) for IEEE 802.11 ad hoc networks. T.Srinivasan[8] et al proposed a novel scheme for data-centric multi-path routing in WSN. Hui Liu[9] et al presented a Genetic Fuzzy Multi-path Routing Protocol (GFMRP). Qi Bing[10] et al presented an improved multicast routing protocol based on fuzzy clustering (FHRouting) to construct a hierarchical topology tree for the routing optimization in overlay network. In this paragraph, it shows that fuzzy logic has never been used in power control of peer to peer communication.

Due to reasons mentioned in two paragraphs above, it would make sense to apply fuzzy logic to power control of peer to peer communication. In this paper, a novel fuzzy algorithm for power control of wireless sensor nodes is presented. In a clustering formation WSN system model, a fuzzy logic controller is used to adjust transmission power adaptively. The result of energy efficiency can be shown in simulation.

The remaining of this paper is organized as follows. The clustering formation WSN system model is proposed in section II. In section III, fuzzy logic controller is discussed which includes fuzzification, fuzzy rules and defuzzification method. Section IV makes an experiment based on Matlab and analyses simulation results. Finally, the conclusions are presented in section V.

II. PROPOSED SYSTEM MODEL

It is rational to suppose the cluster WSN is formed according to certain clustering algorithm. Now, just a peer to peer communication system model is needed, which discuss the communication between sensor node and cluster head. In WSN, it should be noted that this model can be applied in other environment, not only in clustering formation network.
The peer to peer transmission power control system is shown as Fig. 1.

In Sending Node, Transmission Module sends data packets with reference transmission power delivered by History Power Module. Adjust Value Receiving Module is used to update history power level in real-time.

In Receiving Node, Receiving Module works in physical layer to receive signals. QoS Extraction Module collects several receiving QoS parameters and Fuzzy Computing Module calculates adjust-value with fuzzy logic controller. The result is delivered to Adjust Value Feedback Module which is in charge of sending adjust-value to Sending Node with a transmission power the same as Sending Node. It assumes that the communication links are bidirectional and symmetric. In that case, fading features of the two channels are related, so Sending Node can get adjust-value successfully.

The key part of this system is Fuzzy Computing Module which works out adjust-value based on receiving QoS parameters. It will be presented in detail in section III.

### III. Fuzzy Logic Controller

In this paper, the transmission power control is realized by a fuzzy logic controller. Fuzzy logic fits best in applications where the mathematical models don’t exist or traditional system models become too complex[11]. The transmission signal attenuation is intricacy and nearly vagueness in WSN. It is hard to decide a proper transmission power for the sending node at a time. Consequently, the fuzzy based approach is a viable option. The model of fuzzy logic controller shown in Fig. 2 consists of fuzzification section, fuzzy set section, fuzzy rule section, fuzzy compute section and defuzzification section.

The fuzzification is the process of transforming crisp values into fuzzy linguistic variables. The membership function is used to associate a grade to each linguistic variable[12].

The membership functions very bad(VBAD), bad(BAD), perfect(PERFECT), good(GOOD) and very good(VGOOD) are defined on each input variable and big step down(BDSTEP), small step down(SDSTEP), tiny step down(TDSTEP), hold(HOLD), tiny step up(TUSTEP), small step up(SUSTEP) and big step up(BUSTEP) are defined on output variable.

#### A. Fuzzification

Learning from another paper[12], Fig. 3 to Fig. 7 show the membership graphs for input variables LQI, RSSI, SNR, data transmission rate(DTR) and output variable ADJ, respectively. Each fuzzy set of inputs or output is described as gauss, trapezium, triangle function or the combination of them[13], because these functions are suitable for real-time operation[14].

The gauss function is defined as follows:

\[
f(x; \delta, c) = \exp\left(-\frac{(x - c)^2}{2\delta^2}\right).
\]

The trapezium function is defined as follows:

\[
f(x; a, b, c, d) = \max(\min(\frac{x - a}{b - a}, 1), \frac{d - x}{d - c}), 0).
\]

The triangle function is defined as follows:

\[
f(x; a, b, c) = \max(\min(\frac{x - a}{b - a}, \frac{c - x}{c - b}), 0).
\]

#### B. Fuzzy Rule

Fuzzy rules drive the fuzzy compute section to produce fuzzy outputs.

It is complex to list all rules, if there are too many inputs. To simplify the description, the following definitions of fuzzy rules are limited in a single input. If necessary, it can be extended to multi-inputs. In practice, selecting a mutable QoS parameter as the single input is reasonable and it will increases the sensitivity of the fuzzy logic controller.

In certain condition, if LQI varies dramatically, two LQI values at different times are selected as the inputs. LQI-NOW is collected from this receiving QoS parameters and LQI-F1 is collected from last receiving QoS parameters. To control the fuzzy computing process, this paper defines 11 fuzzy rules, which are expressed as follows:

- If (LQI-NOW is VBAD) then (ADJ is BUSTEP).
- If (LQI-NOW is VGOOD) then (ADJ is BDSTEP).
• If (LQI-F1 is VGOOD) and (LQI-NOW is BAD) then (ADJ is TUSTEP).
• If (LQI-F1 is GOOD) and (LQI-NOW is BAD) then (ADJ is TDSTEP).
• If (LQI-F1 is VBAD) and (LQI-NOW is GOOD) then (ADJ is TDSTEP).
• If (LQI-F1 is BAD) and (LQI-NOW is GOOD) then (ADJ is TDSTEP).
• If (LQI-F1 is GOOD) and (LQI-NOW is GOOD) then (ADJ is SDSTEP).
• If (LQI-F1 is VGOOD) and (LQI-NOW is GOOD) then (ADJ is SDSTEP).
• If (LQI-F1 is VBAD) and (LQI-NOW is BAD) then (ADJ is SUSTEP).
• If (LQI-NOW is PERFECT) then (ADJ is HOLD).

In defuzzification, we use centroid of area method[12]:

\[
adj = \frac{\sum_{i=1}^{7} \mu_i(u_i)u_i}{\sum_{i=1}^{7} \mu_i(u_i)}. \tag{5}
\]

In most instances, centroid of area method is better than other methods, because it delivers precise value for the crisp output \(adj\).

**C. Defuzzification**

The fuzzy logic controller is designed based on Mamdani model. The transformation from a fuzzy output (\(ADJ\)) to a crisp value (\(adj\)) is called defuzzification.

\(ADJ\) is a fuzzy set:

\[
ADJ = \{u_1, u_2, u_3, u_4, u_5, u_6, u_7\}. \tag{4}
\]
IV. SIMULATION AND PERFORMANCE ANALYSIS

We construct a virtual clustering WSN environment in Matlab. It is simple, but is a simulation of real world.

The free-space propagation model is chosen as channel model[12]:

\[ P_T + G_T + G_R - \text{Los} = P_R, \tag{6} \]

where \( P_T \) is the transmission power of sending node, \( G_T \) and \( G_R \) are the transmission antenna gain and receive antenna gain, respectively. \( P_R \) is the receiving power of receiving node. The link loss can be determined by (7)[15]:

\[ \text{Los} = K + 20\log D + 20\log F, \tag{7} \]

where \( D \) is the distance between two nodes, \( F \) is the transmission frequency and \( K \) is a adjustable factor rely on environment. As in (8), we define the relation between the receiving power \( P_R \) and the link quality indication \( LQI \):

\[ LQI = 1.516P_R + 192.3 \tag{8} \]

As a special case, according to Network Specification Revision 10 Version 1.00[16] submitted by ZigBee Alliance, we select the LQI of this packet and the LQI of last packet as inputs. To shorten simulation time, we define the energy of the sensor node is 10J which is only 0.1 percent of the energy common 3.6V 800mAh Li-ion Battery contains. We assume the cluster head contains more energy than sensor node, so it has relatively infinite energy. Receiving sensitivity of the receiving node is -95dBm. The transmission and receive antenna gains are both 10dBm.

We do two simulations. In the first simulation, we just deploy two nodes, and make the distance between them longer and longer. In the second network simulation, we deploy a large number of sensor nodes in an area. Several cluster heads are selected from sensor nodes according to certain clustering formation algorithm. In fact, we do not care what algorithm is chosen. The sensor nodes are moving randomly and the cluster heads are fixed. Each sensor node belongs to the nearest cluster head. The communication between two sensor nodes must via their cluster heads. The communication route is: one sensor node, its cluster head, the cluster head of another sensor node, another sensor node.

In the first simulation, we suppose that the distance between two sensor nodes, called A and B, is increasing from 1 meter. Every 5 seconds, A sends a packet which costs 1 second and some energy. When receiving the packet, B works out the adjusted value of transmission power and feedbacks to A, which also costs 1 second and some energy. The next cycle, A sends a packet with adjusted transmission power. Cycles go on until the energy is exhausted. The simulation compares fuzzy power control method with fixed transmission power method on the performance of PER. The results are demonstrated in Fig. 8 (initial transmission power 7dBm) and Fig. 9 (initial transmission power -8dBm).

From Fig. 8 and Fig. 9, we can get two conclusions. First, with distance increasing, packet error event happens later in fuzzy power control method than that in fixed transmission power method. Second, with decreasing of initial transmission power, the no packet error distance is a fixed value for the former method, while it reduces for the latter method. The conclusions mentioned above indicate that the former method has longer and more stable communication distance. Its advantage is making the sending node hold an optimum and mutable transmission power which brings packet error rarely in any environment.

In second network simulation, we deploy 100 sensor nodes randomly and 4 cluster heads fixedly in 100m*100m area. Every 5 seconds, 10 sending nodes and 10 receiving nodes are selected randomly and move randomly. Each sending node sends 10 packets to certain receiving node via its cluster head. Both sending and receiving cost some energy. Certain node will be stripped from network when energy is exhausted. When the number of existing nodes is less than 30, the network collapses. Fig. 10 compares fuzzy power control method with fixed transmission power method on the performance of Network Survival Time.

In Fig. 10, it can be seen that network survival time of fuzzy power control method is twice longer than that of fixed transmission power method. In order to meet certain
QoS, the latter method must use higher transmission power, because it does not know which transmission power is proper. However, in any varying condition, the former method can adjust transmission power to optimum value by some cycles of fuzzy computing.

![Network Survival Time Performance Comparison](image)

Fig. 10. Network Survival Time Performance Comparison.

V. CONCLUSIONS

In this paper, a novel power control algorithm based on fuzzy logic is proposed. Simulation results show that this approach could improve robustness and prolong survival time of the network. However, this algorithm does not fit every case. It is just a peer to peer algorithm and the performance of fuzzy logic controller depends on the subjective opinion of designer. So, how to expand application context to complex environment and how to find out a comparatively objective design of fuzzy logic controller are what the future work should focus on.

REFERENCES