A Safety Review on Fuzzy-based Relay Selection in Wireless Sensor Networks

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Abstract

A Wi-Fi has been able to accomplish great transmission due to its co-transfer mode. Each wireless network node has to rely on the way to achieve its mission of information transmission. In unattended sensing network environment, the relay process of how to select an appropriate relay nodes can adjust power consumption and communication quality, so it has attracted a lot of research attention and considerable results. Yang and Brante are few of researchers in recent years. They applied the fuzzy inference system to the relay selection algorithm, which was confirmed to have a good performance. In this study, a safety assessment method for fuzzy relay selection algorithms has been introduced. and introduce the safety performance of Yang's and Brante's method. Then this article can be expected to extend the depth and breadth by the future research.

Keywords: Fuzzy relationship rule, relay selection algorithm, wireless sensor network

1 Introduction

This study focuses on the issue of saving sensor networks. The need for energy-saving of sensor networks is required, because it was difficult or impossible to charge energy in some application areas at unattended sensing nodes. In this case, the whole sensing network life cycle was dependent on battery power [24, 31]. In the energy-saving study area, it is usually divided into three areas: sensing, aggregated data and communication [11, 12]. The relay selection algorithms belong to the field of communications. The research in this area pointed out that the biggest action of power consumption in the wireless sensor nodes are transmitted and received [3], and most effective energy-saving strategy is to use sleep mode [7]. This strategy allows a node only to transmit and receive when it?s necessary. However, how to select the most appropriate partners [1] from candidate relay gateway nodes in staggered complex wireless sensor networks is to avoid transmitting and receiving the same information by all possible nodes. Repeating each other's electricity consumption will result in lower overall network life cycle. That was still a very important issue [6, 31]. Specifically, the trade-off problem [2] was how to balance the communication quality and remainder power between nodes, and still able to maintain optimal network life cycle.

Cover and ElGamal proposed the concept of three relay architecture [5] first in 1979. The existing study of relay selection techniques can be classified as a measure, effectiveness threshold and adjustment patterns opportunity. For communication nodes to exchange information point of view, it can be divided into two types of forms and competitions [23]. Recently, for the fuzzy relay selection algorithm, it is based on fuzzy sets to use fuzzy rule base and defuzzification architecture out of the relay selection algorithms. Yang made the first algorithm based fuzzy relay selection, and proved the effectiveness of the use of fuzzy theory that can make performers get traditional relay selection algorithm [28]. Brante structure is a more complete fuzzy relay selection algorithm. It focuses on the balance of nodes between the quality of communication and remainder power, and optimizing the efficiency of the algorithm [4]. This paper suggests that poor design of fuzzy relay selection algorithms is most likely to suffer an attack [22]. If the algorithm without adjustment, then it would choose a high power, high communication state parameters. It will come to the opposite effect, and lose the purposes to reach energy-saving and adjust communication in a power attack mode. Therefore, that needs to be properly analyzed to protect its safety.

This paper are organized as follows: Section 2 describes the relay selection algorithms, including the fuzzy relay selection algorithms proposed by Yang and Brante. Section 3 describes a safety test system. Section 4 is to analyze the results of Yang and Brante algorithm in a safety test system. Section 5 is about future research. The last section is to make a conclusion.

2 Fuzzy Relay Selection Algorithm

Yang [28] and Brante [4] proposed a fuzzy relay selection algorithm. The algorithm has shown better trade-off than traditional effect. This section describes a fuzzy system architecture of wireless sensor networks, and the research methods proposed by Yang and Brante who used the fuzzy rule base system by this architecture.

2.1 Fuzzy Based Relay Selection Algorithm

The fuzzy inference system has first started since 1965. When Zadeh published the fuzzy logic and created the fuzzy theory [29, 30]. It has been developed over the years. Those theoretical methods included: the membership function, fuzzy, fuzzy inference rule and defuzzification [21]. The well known MATLAB platform has built based on the Foundations of Fuzzy Logic to specificly practice Mamdani [17, 18] and Sugeno's theory [17, 26]. Moreover, MATLAB provides an easy-to-operate graphical interface [10] with Fuzzy Logic Toolbox. Such a complete modeling environment has become a favorite tool of researchers [25].

A typical fuzzy inference system architecture built on MATLAB as in Figure 1.

Figure 1: A block diagram of a typical fuzzy inference system

A simple instance exercises of typical fuzzy inference system on MATLAB is shown in Figure 2. It accounts for the situation of fuzzy relay selection algorithm on wireless sensor networks. The construction of its contents is shown in the following subsections.

2.1.1 Define the Variables

This example is a scenarios for battery-powered wireless sensor networks. The main application of the fuzzy controller is to regulate power consumption and communication status. Therefore, Two input variables are defined as the *Re* (remaining energy) and *CSI* (Chanel State Information). One output variable is defined as Select (probability of a candidate node for forwards select). Its representations are as follows: (1) variable domain range, (2) variable parameter, (3) parameter semantic and (4) member function.

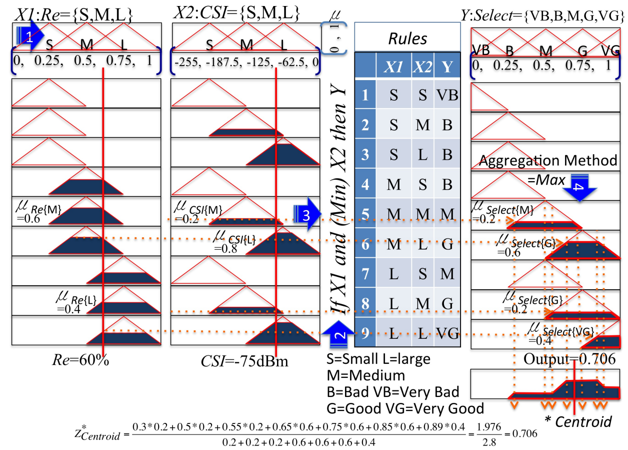

Figure 2: Typical instance of a fuzzy inference system on MATLAB

Variable Domain Range:

$$\begin{aligned} Re = & \quad [0 \sim 100\%] \\ CSI = & \quad [-255dBm \sim 0dBm] \\ Select = & \quad [0 \sim 100\%] \end{aligned}$$

Variable Parameter:

$$\begin{aligned} Re = & \quad \{\mathbf{S} : Small, \mathbf{M} : Medium, \mathbf{L} : Large\} \\ CSI = & \quad \{\mathbf{S} : Small, \mathbf{M} : Medium, \mathbf{L} : Large\} \\ Select = & \quad \{\mathbf{VB} : VeryBad, \mathbf{B} : Bad, \\ & \quad \mathbf{M} : Medium, \\ & \quad \mathbf{G} : Good, \mathbf{VG} : VeryGood\} \end{aligned}$$

Parameter Semantic:

$$\begin{aligned} Re = & \quad \{Lesspower, Mediumpower, Highpower\} \\ CSI = & \quad \{Badsignal, Mediumsignal, Goodsignal\} \\ Select = & \quad \{Verybad, Bad, InterMedium, Good, \\ & \quad Verygood\} \end{aligned}$$

Member Function:

$$\begin{aligned} Re\{\mathbf{S}\} = & \quad trimf(X1 : 0, 0.25, 0.5) \\ Re\{\mathbf{M}\} = & \quad trimf(X1 : 0.25, 0.5, 0.75) \\ Re\{\mathbf{L}\} = & \quad trimf(X1 : 0.5, 0.75, 1) \\ CSI\{\mathbf{S}\} = & \quad trimf(X2 : -255, -187.5, -125) \\ CSI\{\mathbf{M}\} = & \quad trimf(X2 : -187.5, -125, -62.5) \\ CSI\{\mathbf{L}\} = & \quad trimf(X2 : -125, -62.5, 0) \\ Select\{\mathbf{VB}\} = & \quad trimf(Y : 0, 0, 0.25) \\ Select\{\mathbf{B}\} = & \quad trimf(Y : 0, 0.25, 0.5) \\ Select\{\mathbf{M}\} = & \quad trimf(Y : 0.25, 0.5, 0.75) \\ Select\{\mathbf{G}\} = & \quad trimf(Y : 0.5, 0.75, 1) \\ Select\{\mathbf{VG}\} = & \quad trimf(Y : 0.75, 1, 1) \end{aligned} \qquad (1)$$

This example used Triangle Membership function (trimf). The input values will belong to a different set, and convert to the μ (membership grade) between 0∼1.

2.1.2 Design a Fuzzy Rule Base

A fuzzy rule base is based on experience and expert knowledge. It's translated to semantic with the control rules as "If X1 and X2 Then Y". The example was divided into three fuzzy parameters. Therefore, it can be deduced to a relation matrix of 3 ∗ 3 input and output in Table 1. Thus, the rule bases are got as nine fuzzy rules:

$$\begin{aligned}
&Rule1 : If\ X1 : Re\{S\}\ and\ X2 : CSI\{S\}\\
&\quad Then\ Y : Select\{VB\}\\
&Rule2 : If\ X1 : Re\{S\}\ and\ X2 : CSI\{M\}\\
&\quad Then\ Y : Select\{B\}\\
&Rule3 : If\ X1 : Re\{S\}\ and\ X2 : CSI\{L\}\\
&\quad Then\ Y : Select\{B\}\\
&Rule4 : If\ X1 : Re\{M\}\ and\ X2 : CSI\{S\}\\
&\quad Then\ Y : Select\{B\}\\
&Rule5 : If\ X1 : Re\{M\}\ and\ X2 : CSI\{M\}\\
&\quad Then\ Y : Select\{M\}\\
&Rule6 : If\ X1 : Re\{M\}\ and\ X2 : CSI\{L\}\\
&\quad Then\ Y : Select\{G\}\\
&Rule7 : If\ X1 : Re\{L\}\ and\ X2 : CSI\{S\}\\
&\quad Then\ Y : Select\{M\}\\
&Rule8 : If\ X1 : Re\{L\}\ and\ X2 : CSI\{M\}\\
&\quad Then\ Y : Select\{G\}\\
&Rule9 : If\ X1 : Re\{L\}\ and\ X2 : CSI\{L\}\\
&\quad Then\ Y : Select\{VG\}
\end{aligned} \tag{2}$$

Table 1: The relation matrix of fuzzy rules base

Re\CSI	**S**	**M**	**L**
S	VB	B	B
M	B	M	G
L	M	G	VG

2.1.3 Fuzzification

Assume the input value is set to Re = 60%, CSI = -75dBm in Figure 2. According to the membership function represented by Equations (1) and (2), the membership grade is obtained: $\mu_{Re\{M\}} = 0.6$, $\mu_{Re\{L\}} = 0.4$, $\mu_{CSI\{M\}} = 0.2$, $\mu_{CSI\{L\}} = 0.8$. Next, the specified rule is based on this instance process Min fuzzy arithmetic with the And of sets operator to output membership function value as shown in Table 2:

2.1.4 Defuzzification

It's not the only value was obtained by the output membership function. In this case, calculated result was using the Max aggregation method and the Centroid method to defuzzification such as follows:

$$\begin{aligned}
Z^*_{Cente} &= \frac{Z^1 + Z^2 + Z^3 + Z^4 + Z^5 + Z^6 + Z^7}{0.2 + 0.2 + 0.2 + 0.6 + 0.6 + 0.6 + 0.4}\\
&= \frac{1.976}{2.8}\\
&= 0.706
\end{aligned} \tag{3}$$

Notes:

$$\begin{aligned}
Z^1 &= 0.3 \times 0.2,\\
Z^2 &= 0.5 \times 0.2,\\
Z^3 &= 0.55 \times 0.2,\\
Z^4 &= 0.65 \times 0.6,\\
Z^5 &= 0.75 \times 0.6,\\
Z^6 &= 0.85 \times 0.6,\\
Z^7 &= 0.85 \times 0.6,\\
Z^8 &= 0.89 \times 0.4.
\end{aligned}$$

The output value of 0.706 was got by the typical fuzzy inference system. If the value is greater than the defuzzification output of other nodes, eventually, this node is selected as the relay node from fuzzy relay selection algorithms in wireless sensor networks.

2.2 Yang's Fuzzy Inference Method

Although fuzzy theory have developed for many years. But it can be applied to regulate power consumption and communication status of a relay selection method in wireless sensor networks only by Yang until 2009. Although the relay selection algorithm by Yang's have assigned the membership function within fuzzy system functions. But it's only using the traditional method of weighted average instead of the fuzzy inference rule and defuzzification process. Yang's fuzzy theory operation is shown in the following subsections.

2.2.1 Define the Variables

Variable Domain Range:

$$\begin{aligned}
Re &= [0 \sim 100\%]\\
CSI &= [-255dBm \sim 0dBm].
\end{aligned}$$

Variable Parameter:

$$\begin{aligned}
Re &= \{\mathbf{All}\},\\
CSI &= \{\mathbf{All}\}.
\end{aligned}$$

Parameter Semantic:

$$\begin{aligned}
Re &= \{\mathbf{Power}\},\\
CSI &= \{\mathbf{Signal}\}.
\end{aligned}$$

Member Function:

$$\begin{aligned}
Re\{\mathbf{All}\} &= trimf(X1 : 0, 0, 1)\\
CSI\{\mathbf{All}\} &= trimf(X2 : -255, -255, 0).
\end{aligned}$$

2.2.2 Design a Fuzzy Rule Base

From the above, Yang uses a single variable parameter. The fuzzy system will create the equivalent of fuzzy input matrix R:

$$R = [\mu_{Re\{\mathbf{All}\}}, \mu_{CSI\{\mathbf{All}\}}].$$

Table 2: Operation results by Min fuzzy method

Re \ ***CSI***	$\mu_{CSI\{S\}} = 0$	$\mu_{CSI\{M\}} = 0.2$	$\mu_{CSI\{L\}} = 0.8$
$\mu_{Re\{S\}} = 0$	Min(0,0)=0	Min(0,0.6)=0	Min(0,0.8)=0
$\mu_{Re\{M\}} = 0.6$	Min(0.6,0)=0	Min(0.6,0.2)= $\mu_{Select\{M\}}(0.2)$	Min(0.6,0.8)= $\mu_{Select\{G\}}(0.6)$
$\mu_{Re\{L\}} = 0.4$	Min(0.4,0)=0	Min(0.4,0.2)= $\mu_{Select\{G\}}(0.2)$	Min(0.4,0.8)= $\mu_{Select\{VG\}}(0.4)$

2.2.3 Fuzzification and Defuzzification

Yang uses the output weights W as a defuzzification operation mechanism:

$$W = (W_{Re} = 0.5, W_{CSI} = 0.5).$$

Finally, the following equation is used to assess the output results to determine a relay node with a maximum value:

$$\begin{aligned} Z &= R \bullet W \\ &= (\mu_{Re\{\mathbf{All}\}} \times W_{Re}) + (\mu_{CSI\{\mathbf{All}\}} \times W_{CSI}). \end{aligned}$$

The simulation of Yang's relay selection algorithm have proved that the network life cycle is improved than a relay selection algorithms which only assess a single network quality with *CSI*. Although Yang method is still using some of the traditional method, the survey of literature [1] for relay selection algorithms has not still categorized the fuzzy system relay selection algorithms as an exclusive categories; Brante said: Yang's research is the first fuzzy system to use relay selection algorithms [4].

2.3 Brante's Fuzzy Inference Method

Brante proposed a distributed relay selection algorithm on wireless sensor networks in 2013. Relative to Yang relay selection algorithm in 2009, Brante's research has been able to use the complete fuzzy systems to control the selection of cooperative nodes. The block diagram of Brante's fuzzy system for relay selection algorithms is shown in Figure 3. Brante's fuzzy theory operated is shown in the following subsections.

2.3.1 Define the Variables

Variable Domain Range:

$$\begin{aligned} Re &= [0 \sim 100\%] \\ CSI &= [0 \sim \infty]. \end{aligned}$$

Variable Parameter:

$$\begin{aligned} Re &= \{L : Low; M : Medium; F : Full\} \\ CSI &= \{W : Weak; A : Average; S : Strong\} \\ Select &= \{VB : VeryBad; B : Bad; \\ &\quad M : Medium; G : Good; \\ &\quad VG : VeryGood\} \end{aligned}$$

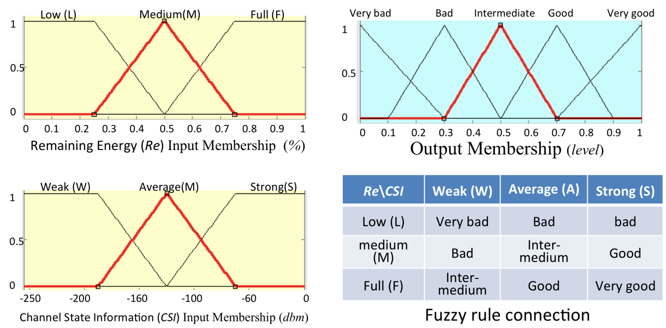

Figure 3: The block diagram of Brante's fuzzy system for relay selection

Parameter Semantic:

$$\begin{aligned} Re &= \{Less\,Power, Medium\,Power, High\,Power\} \\ CSI &= \{Bad\,Signal, Medium\,Signal, Good\,Signal\} \\ Select &= \{VeryBad, \\ &\quad Bad, \\ &\quad Medium, \\ &\quad Good, \\ &\quad VeryGood\}. \end{aligned}$$

Member Function: Use Trapezoid Membership function (trapmf).

$$\begin{aligned} Re\{\mathbf{L}\} &= trapmf(X1 : 0, 0, 0.25, 0.5) \\ Re\{\mathbf{M}\} &= trapmf(X1 : 0.25, 0.5, 0.5, 0.75) \\ Re\{\mathbf{F}\} &= trapmf(X1 : 0.5, 0, 75, 1, 1) \\ CSI\{\mathbf{W}\} &= trapmf(X2 : -255, -255, -187.5, \\ &\qquad -125) \\ CSI\{\mathbf{A}\} &= trapmf(X2 : -187.5, -125, -125, \\ &\qquad -62.5) \\ CSI\{\mathbf{S}\} &= trapmf(X2 : -125, -62.5, 0, 0) \\ Select\{\mathbf{VB}\} &= trapmf(Y : 0, 0, 0, 0.3) \\ Select\{\mathbf{B}\} &= trapmf(Y : 0.1, 0.3, 0.3, 0.5) \\ Select\{\mathbf{M}\} &= trapmf(Y : 0.3, 0.5, 0.5, 0.7) \\ Select\{\mathbf{G}\} &= trapmf(Y : 0.5, 0.7, 0.7, 0.9) \\ Select\{\mathbf{VG}\} &= trapmf(Y : 0.7, 1, 1, 1). \end{aligned}$$

2.3.2 Design a Fuzzy Rule Base

Table 3 is Brante's $3*3$ relationship matrix of input and output. Therefore, the rule bases will get 9 fuzzy rules.

Table 3: The relation matrix of Brante's fuzzy rule

Re\CSI	**W**	**A**	**S**
L	VB	B	B
M	B	M	G
F	M	G	VG

2.3.3 Fuzzification and Defuzzification

The Aggregation Method of Brante's fuzzy systems used Max and Centroid for defuzzification. As the general, a fuzzy systems often output a same value when defuzzification results in the same value. A random selection method is used to determine a relay node by Brante's algorithm. Brante's method get a better simulation results when comparison with a traditional random selection relay algorithm and an opportunity chosen relay algorithm, which also play a simple calculation mechanism of fuzzy systems and extend the network life cycle.

Yang and Brante officially used the fuzzy theory for relay selection algorithm in wireless sensor networks. This paper use the same framework to resolve its methodology. Comparing their architecture with a typical fuzzy system, the difference is shown in Table 4.

3 Safety Testing Systems

This section describes a relay selection algorithms based on fuzzy systems in wireless sensor networks to evaluate when it suffered an attack in an unsafe environment. Some literature points out that the biggest threat in the battery-powered wireless sensor networks are Sinkhole Attacks, Wormhole Attacks and Sybil Attacks. It directly affects the algorithms results to regulate power consumption and communication quality [22]. A common threat in attacks mode is power consumption [15]. It's often increasing the burden of relaying nodes, when a sending packet was dropped by an attacked node. Therefore, the adjusting mechanism of algorithm will lose balance. Then it can't reach the expected purpose to extend the network life cycle.

Since Yang's and Brante's proposed methods are assumed to be performed in an unattacked state. In fact, the effectiveness of the security is different between each designed fuzzy-based inference rules system, when it suffers a power attack.

Considering this scenario, the attacker increase antenna power of attack nodes , and expand its transmission range, or forge remaining power status or otherwise supplemental power of attack nodes, so that adjacent nodes mistake it reliable cooperative node, and then select the attack node as a relay node.

Therefore, if an algorithm doesn't consider these cases, the mechanism of selection algorithm can easily be exploited by attackers. It has consumed too much power without any awareness. In order to evaluate efficacy and safety of different relay selection algorithms designed by fuzzy-based inference rules, this study design a security testing systems, and assess the method of construction mode with fuzzy-based rules base in wireless sensor network. It is described as follows:

The security testing System includes five components: network architecture, signal processing, power consumption, security assessment of simulated attacks and simulation platform.

3.1 Network Architecture

As the study points out Brante's method has relatively good performance. Therefore, this study used Brante's architecture in networks [4] as shown in Figure 4 and Table 5.

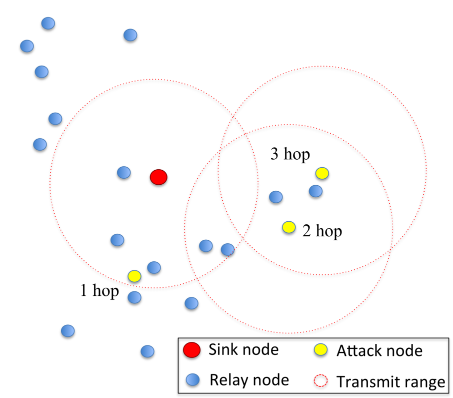

Figure 4: Simulation topology in wireless sensor networks

3.2 Signal Processing

The signal processing follows the IEEE 802.15.4 specification, and use the data transfer mode [9] in networks. Mixing with white noise processing in simulation [14, 19], it assumes that the receiver sensitivity is -85dBm, and the maximum transmission distance is 200M.

3.3 Power Consumption

The power consumption is using the first order radio model radio power consumption model [8, 13] as shown in Figure 5 and Table 6, and ignoring the tiny fixed detection power calculation factor on electricity consumption [3, 7].

Table 4: Comparing the architecture method with Yang's and Brante's fuzzy system

Fuzzy Systems Construction	Yang's system	Brante's system
Variables domain range	$Re = [0 \sim 100\%]$ $CSI = [-255dBm \sim 0dBm]$	$Re = [0 \sim 100\%]$ $CSI = [-255dBm \sim 0dBm]$
Variable parameters	2 inputs are all divided into 1 set undefined output	2 inputs are all divided into 3 sets 1 output is divided into 5 sets
Membership function	trimf	trapmf
Fuzzy rules base	Undefined	9 sets
Defuzzification	Traditional	Centroid

Table 5: Simulation parameters in networks

Network topology	Mesh topology
Node numbers	20 nodes (including Sink)
Transmission distance	200 M
Physical layer MAC protocol	802.15.4
Maximum number of network layers hops	3 layers
Data transfer mode	Beacons

Table 6: Power consumption in model

Operational unit	**Power consumption**
Transmitter electronics (E_{Tx_elec}) **Receiver electronics** (E_{Rx_elec}) E_{Tx_elec}=E_{Rx_elec}=E_{elec}	$50nJ/bit$
Transmission amplifier (E_{amp})	100 $pJ/bit/m^2$

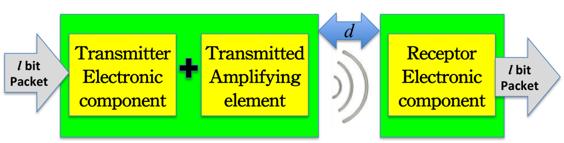

Figure 5: Radio power consumption model

3.4 Simulated Attack and Safety Assessment

The safety effectiveness of relay selection algorithm with fuzzy-based inference system was assumed that environment status were unprotected or lost protection in network, and its defensive system didn't even start yet. An attacked node set its each positions in 3 hop layers in Figure 4, separately performing four different attack patterns to construct the evaluation of system modules as shown in Table 7.

The simulation was set under the same network topology. All of 20 nodes starts attack after 50 rounds and ends attack after at 200 rounds. An attacked number was counted by relay nodes in selection algorithm. And the safety rate was indicated as the security level of algorithms by conversion as follows:

$$Safety\ Ratio = \frac{candidate\ attack\ numbers - attacked\ numbers}{candidate\ attack\ numbers} \times 100\%.$$

Therefore, the lower total number of attacks were the better performance of hedging function, whereas the higher total number of attacks were the worst performance of hedging function. In contrast, an algorithm with the better performance of hedging function able to extend the network life, because they can avoid the attacked nodes and without waste retransmission for failure relay. Thus, an algorithms can achieve its purposes for balancing power consumption and communication quality.

3.5 Simulation Platform

The simulation platform used the MATLAB Design and simulate fuzzy logic systems [10]. It can execute two kinds fuzzification connection methods of And-Min or Or-Max and five kinds defuzzification approachs about Centroid (center of gravity method), Bisector (the qualitative method), Lom (maximum membership degree method), Mom (middle membership degree method), and Som (minimum membership degree method). As long as the

Table 7: Consumption attack type with *CSI* and *RE*

Type	Patterns and metrics (*CSI* & *Re*)	
1	Signal attack patterns	The attacked nodes utilize the enhanced power mode to change the signal value of attacked nodes in select-right nodes
2	Power attack patterns	The attacked nodes utilize the enhanced energy mode to change the remaining energy value of attacked nodes in right selected nodes
3	Hybrid attack patterns	The attacked nodes utilize the enhanced the power and energy mode to change the signal and remaining energy value of attacked nodes in right selected nodes
4	Uncooperative attack patterns	The attacked nodes themselves don't change the power and energy mode, and don't change the signal and the remaining energy value of attacked nodes in right selected nodes. It plays the role of uncooperative and doesn't reply the data to receive the information

testing system was replaced other fuzzy inference module. Any relay selection algorithm of fuzzy systems can operate in this testing system. The testing system will store all candidate nodes information in different tests of attack patterns. A single fuzzy system was displayed in face different attack patterns from the real work. There are nearly got ten thousand of records. To aggregated these cumulative test data's. Thats some valuable experience for fuzzy system to analysis the safety of relay selection algorithms. Because the rules base of fuzzy inference system is very dependent on experience of expert and practical operation [26]. Extracting of those experiences will be transformed into fuzzy-base algorithm to improve its safety policy in the future work.

4 The Safety Test Results of Existing Fuzzy Relay Selection Algorithms

This section describes the test results of Yang's and Brante's fuzzy-based relay selection algorithms in wireless sensor networks when they faces three attack positions and four attack patterns in the study testing system.

Figure 6 shows the overall performance of the existing algorithms of Yang and Brante. First, the 2hop safety rate is always higher the 1hop when the position was launched by the attacker. The outer layer is higher by 4% than the inner layer of safety rate. It's higher by 3.8% of Brante's algorithm due to the reason of the relationship between network topology. The inner layer of the network transmission load will come naturally heavier than the outer layer. That means the inner network attackers have obtained the highest efficiency, too. Further, the 3hop at outermost has 100% safety rate due to the network environment factors. There is no difference between Yang's and Brante's algorithms. This also explains the outermost layer of the network, so it doesn't need to pass as a relay node. Therefore, the risk is close to zero.

For hedging effect view of the algorithms, Brante's algorithm is higher than 0.9% of Yang's algorithm under 1hop attack. It's also higher 0.7% under 2hop attack.

Therefore, hedge effectiveness of test results of Brante simulation algorithm is better 0.8% better than Yang's algorithm in average.

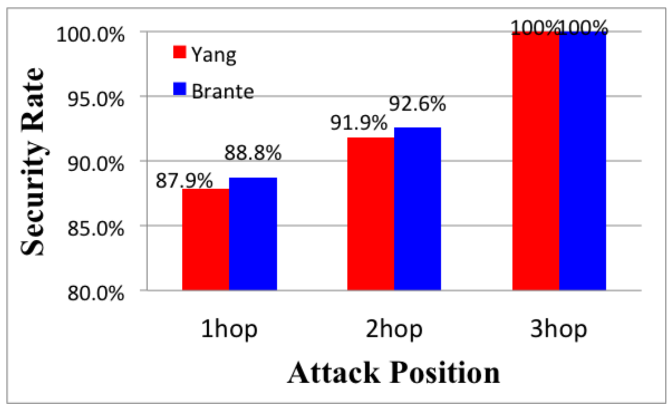

Figure 6: Existing algorithms, Attack Position, hedge effectiveness

Figures 7 and 8 show Yang's and Brante's algorithms facing four kinds of attack patterns to hedge effectiveness under attack in 1hop position and 2hop position. Those relay selection algorithms are concerned with the same fuzzy inference developed in wireless sensor networks, and whose defense strength order was: Type4 (*Dicard*) > Type2 (*Re*) > Type1 (*CSI*) > Type3 (*CSI* + *Re*), when Yang's and Brante's algorithms encounter four kinds of attack patterns. That explains the Type3 attack patterns are the most difficult to guard against by mixed signal and power. The next was the Type1 attack patterns by the signal, next was the Type2 power attack patterns, and, finally, the Type4 attack patterns are not so much affected by uncooperative loss threat.

When viewed in Figures 7 and 8 at same time, it shows the hedge effectiveness in Yang's and Brante's algorithms. It's more difficult to distinguish the difference between algorithms when it is more to outer layer of the network. This phenomenon can be applied to all the fuzzy-based relay selection algorithms for the safety assessment in wire-

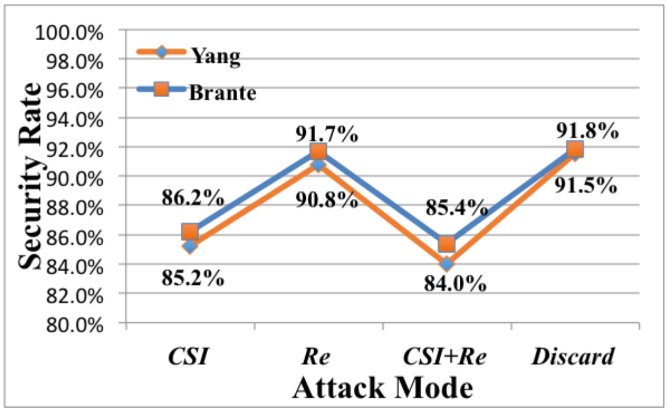

Figure 7: Existing algorithms, Attack Mode by 1 hop Position, hedge effectiveness

less sensor networks.

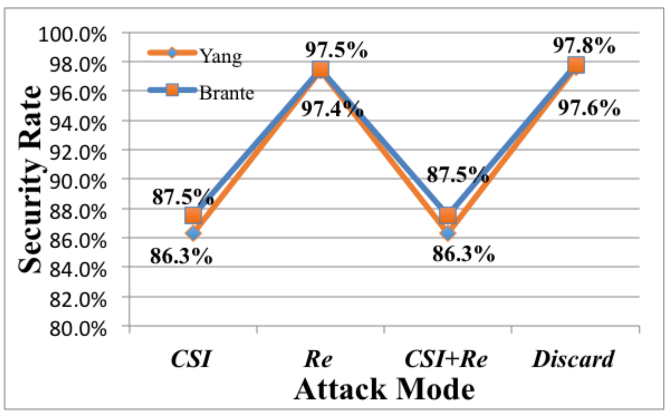

Figure 8: Existing algorithms, Attack Mode by 2hop Position, hedge effectiveness

5 Future Research

The fuzzy theory shows good performance. It was originally regarded as the best of the tools in the household appliance and automatic control. But most scholars generally believe that fuzzy is not productive to safety. Luckily, Yang and Brante integrated the fuzzy theory with relay selection algorithms in wireless sensor networks. And they gained considerable achievements, so they pioneered out the research-oriented. This section will present a number of research directions to let interested scholars sustain research results in this field.

5.1 Fuzzyfication and Defuzzyfication Methodology

Because Yang and Brante used different fuzzyfication and defuzzification methods (Table 8). Those show different performance results on the simulation testing. In the methodology, Table 9 showed output results by the typical architecture of variable parameter rule base in Figure 2. There are two kinds connection methods, And-Min and Or-Max, for input and output, and five kinds defuzzification methods, Centroid, Bisector, Lom, Mom and Som, between the inference process; perhaps the value order was the same, but after the inference, the results would have been completely different because they used differences methodology. When they choose on doctrinal situation which get interaction between fuzzy membership functions and fuzzy rules base, the calculation results are very different from the traditional linear algorithm.

Therefore, we study the difference hedge effectiveness in the attack state when they used different fuzzification and defuzzification methods in the same domain [16] to find or apply existing algorithms, thereby obtaining more suitable methodology for fuzzy inference system. Even to import C-Mean clustering or variable domain range in fuzzy theory [20]. The formation of strategic inference rules will contribute to the development of high safety relay selection algorithms in wireless sensor networks.

5.2 Fuzzy Rules Base

The core value of the fuzzy rules base is to translate a control rule of linguistic with "If X1 and X2 Then Y" based on experience and expert knowledge. Under this criterion, the relationship between inputs and outputs all rely on control rules. Usually, if the input is divided into three fuzzy parameters, there will be deduced nine fuzzy rules from 3 * 3 matrix of input and output relationship. How detailed should the rule base be controlled? The affect was complete limited by the number of input variables and the division of output number. Therefore, the study of membership function can focus on these numbers to make the difference and develop specific rule base of relay selection algorithm in wireless sensor networks which accumulate sufficient data pass through the relay from simulation. After all, the fuzzy rule base is not imagined, it needs to have the support of big data in order to derive a practical and effective experience and knowledge.

Table 8: Academics using fuzzification and defuzzification

Methods √ Used × Unused ∼ Similar		**Yang**	**Brante**
Fuzzification Connection	And-Min	×	√
	Or-Max	×	×
Defuzzification	Centroid	×	√
	Bisector	×	×
	Lom	×	×
	Mom	∼	×
	Som	×	×

Table 9: Example of fuzzy inference rule base

Input Re	Input CSI	Connection	Defuzzy	Output	Defuzzy shown
60 %	-75 dBm	And-Min	Centroid	0.706	
			Bisector	0.73	
			Lom	0.95	
			Mom	0.75	
			Som	0.65	
		Or-Max	Centroid	0.545	
			Bisector	0.55	
			Lom	1	
			Mom	0.594	
			Som	0.2	

5.3 Fuzzy Feedback Control System Parameters

Figure 9 is a diagram of fuzzy-bases feedback control system [27]. The purpose of the control system is to maintain the y_P output within the range of the SP set point. The controller is adjusted with the e of deviation and the Δe of change deviation as follows:

$$e(n) = SP(n) - y_p(n)$$
$$\Delta e = e(n) - e(n-1) = -(y_p(n) - y_p(n-1)).$$

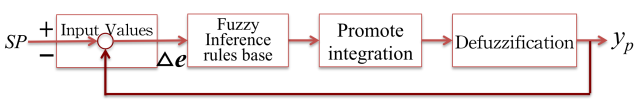

Figure 9: Basic fuzzy feedback control system diagram

The study on fuzzy feedback mechanism could control a relay selection algorithm to maintain security within a certain degree. Then it's unlikely to bog down under the attack and obtain stop-loss effect.

6 Conclusion

The relay process is a noteworthy topic about safety of relay selection algorithm in an unattended sensing network environment. This paper explored the use of fuzzy theory in a relay selection algorithm framework and focused on existing research to balance between communication quality and consuming energy in a wireless sensor network. In order to consider the safety for a fuzzy-based relay selection algorithm, safety testing and evaluation systems were also constructed in wireless sensor networks to analyze the safety effectiveness of existing algorithms about Yang and Brante. In future studies, this paper proposes three main directions. It mainly hopes to make more attention and progress study based on a fuzzy theory in relay selection algorithm. It will improve the research results to follow this type of rely selection algorithms out from prevention systems and protection systems.

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