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Distributed Full Coverage WSN Protocol Based on Energy Self-Aware

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Abstract

With maximizing the coverage time by designing effective algorithm being the core problem for large-scale network, a kind of distributed energy-aware and coverage-aware full-coverage WSN routing protocol (DEAOP) is proposed in this paper. Protocol put forward in this paper adopts the cluster technology. Firstly, divide the sensor nodes into different clusters, with each cluster selecting the cluster head (CH) according to residual energy of the nodes and overlapping degree of the coverage area, and other nodes serve as member nodes of the cluster. Secondly, establish the main data transmission line constituted by cluster head CH. The transmitted data, together with the cluster head CH, is applied to calculate the cost of neighbor cluster head, and nodes with higher cost can be taken as the forwarding node for next group of data. The cost function contains relevant information on residual energy of the nodes and path loss; hence, the higher the cost is, the greater the residual energy and the lower the path loss will be. In this case, nodes with less residual energy will not become invalid prematurely due to being selected as the cluster head CH, thus avoiding the resulting short service life of network and balancing the network energy consumption. Finally, simulate the protocol and analyze its performance in network service life, coverage rate and energy consumption. The simulation results indicate that protocol proposed in this paper can lower the energy consumption and prolong the network service life, thus improving the coverage rate.

Keywords*: Network protocol; Energy-aware; WSNs; Routing; Coverage rate; Sensor node*

1. Introduction

As a network mechanism in which data transmission is carried out by wireless communication, Wireless Sensor Network (WSN) is constituted by a large number of sensor nodes, with each node distributed in the monitoring area. Various sensor nodes in the network can collect, calculate and analyze the information on relevant objects in the network coverage area. In general, sensor nodes distributed randomly are deployed in the area where monitoring is required; however, since the density of these nodes is relatively high, it also brings the problem of high redundancy. To lower the impact of sensor network abnormality on normal operation of the network, scholars have put forward many coping algorithms. For instance, Rodrigo.R [3] *et al.* put forward a kind of algorithm for sensor network abnormality searching based on a refreshing mechanism for regional interaction characteristics. In this algorithm, the mode of periodic characteristic sampling was adopted to refresh the regional characteristics, thus quickly extracting the aggressive behavior of abnormal nodes. However, this kind of searching algorithm can only achieve recursion of the past abnormal aggressive behavior, and frequent updating of nodes can easily lead to serious misjudgment, thus lowering the adaptability of the algorithm. Li.H.T [4] *et al.* proposed a kind of algorithm for sensor network node searching based on an isolating detection mechanism for abnormal behavior. This algorithm adopted the

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partitioned mode, and once abnormality was found in an area, the isolating mechanism would be quickly started up, thus reducing the harm caused by such abnormality to the greatest extent. In this algorithm, however, no adequate consideration has been taken into the node density distribution; when the nodes are distributed in high density, a large number of normal nodes will be divided into the isolated area, thus leading to a large-scale node paralysis in the network. Ning.H.S [5] *et al.* put forward a kind of algorithm for sensor network abnormality discrimination based on a data watermarking discrimination mechanism. In this algorithm, irrevocable temporary watermark was added to the data message, thus lowering the possibility of abnormal nodes sneaking into disorderly. Nevertheless, this algorithm requires that all the data messages sent out by nodes should be added with watermark, and when the network data flow is relatively large, complexity of the algorithm will be increased, with a rising trend in data transmission delay in the network.

2. Sensor Network Model

In consideration of the fact that the sensor network, during deployment, often adopts the sensor based on wireless data exchange mode as the network node, and these nodes complete the networking [6] by adopting the random distribution mode, once an abnormal situation occurs, abnormal information perception can be achieved by the self-provided transceiver antenna and the wireless perception mode. For convenience sake, assume that nodes of the entire sensor network are distributed within the $N \times N$ rectangular region [7]. With regard to sensor network node *i*, provided that its perceptual position within the above-mentioned rectangular region is (x_i, y_i), as is shown in Figure 1; when any abnormality of the node is detected, the central node *j* can be set as the detection node (coordinate as (x, y)),

$$P(i, j) = 1, |i, j| < R \quad (1)$$

Where, $P(i, j)$ is the detection probability, $|i, j|$ represents the physical distance between *i* and *j*, while R represents the optimal perceptual radius of central node *j*:

$$|i, j| = \sqrt{|x_i - x|^2 + |y_i - y|^2} \quad (2)$$

According to Model (1) and Model (2), a judgment can be made in whether the abnormality in node *i* can be detected. If after being processed by Model (1), detection probability of all the network nodes is 1, it indicates that the sensor network is in a perceptible state. Otherwise, the partitioned mode needs to be adopted, and different detection nodes need to be set in different partitions to ensure that entire network is in a perceptible state.

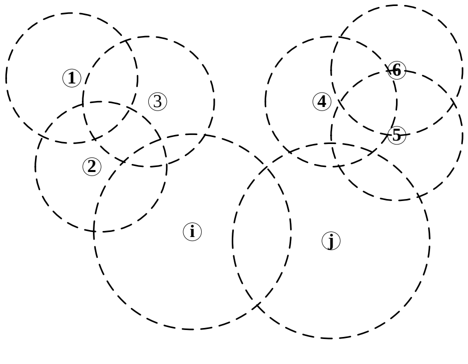


Figure 1. Schematic Diagram of Sensor Network Node Coverage

3. Full-coverage Route of Capacity-aware Network

In WSN, failure of sensor nodes will lead to coverage holes and degrade performance of the entire network. If a sensor node fails, other nodes should move to make up the blind sensing area caused by failure of such node, thus maintaining performance of the entire network [8-9]. In the DEAOP algorithm, therefore, each sensor node, on a regular basis, sends Heartbeat Message to the neighbor nodes to inform them of their working state. If the neighbor nodes fail to receive the Heartbeat Message within a certain period, it indicates that the node may be invalid. Where a sensor node receives the signal from other nodes, whether the node fails or not can be judged according to formula (1). When the signal RSS is less than the threshold value N_{th} , the node can be judged as invalid node. Once an invalid node is detected, other nodes shall move in a proper way. As is shown in Figure 2, failure of sensor node F leads to coverage hole, and in this case, other nodes need to move appropriately.

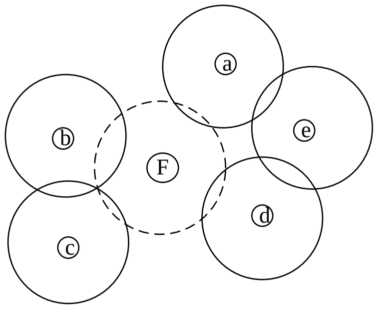


Figure 2. Schematic Diagram of Invalid Node

Where an invalid node is detected, it is required to move a node from the neighbor nodes, for the purpose of minimizing the coverage-free area. As is shown in Figure 4, invalid node F has many neighbor nodes, and there is a chance that movement of a neighbor node can minimize the coverage-free area.

Therefore, the DEAOP algorithm should be adopted to select the appropriate mobile node. In the RCH-FL algorithm, neighbor nodes will firstly select the most appropriate mobile node [10] by adopting the FLS2 (Type-2 Fuzzy logic System), and then FLS will, in accordance with the node energy E, distance d from the hole area and coverage redundancy ξ_i , select the optimal mobile node. Finally, the target location for the mobile node will be determined by adopting FLS1. Model for whole process of the RCH-FL algorithm is shown in Figure 3.

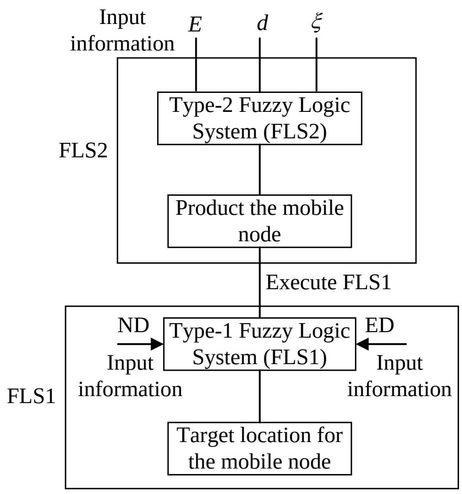


Figure 3. FL-Based RCH-FL Algorithm Model

FLS2 is constituted by three input and one output language variables, and the output variable represents the possibility of the sensor node being selected:

$$T(\lambda) = \{Very\,high, high, Medium, low, very\,low\} \quad (3)$$

Subjection degree of the energy E, distance d from the hole area and coverage redundancy ξ_i is shown in Figure 4.

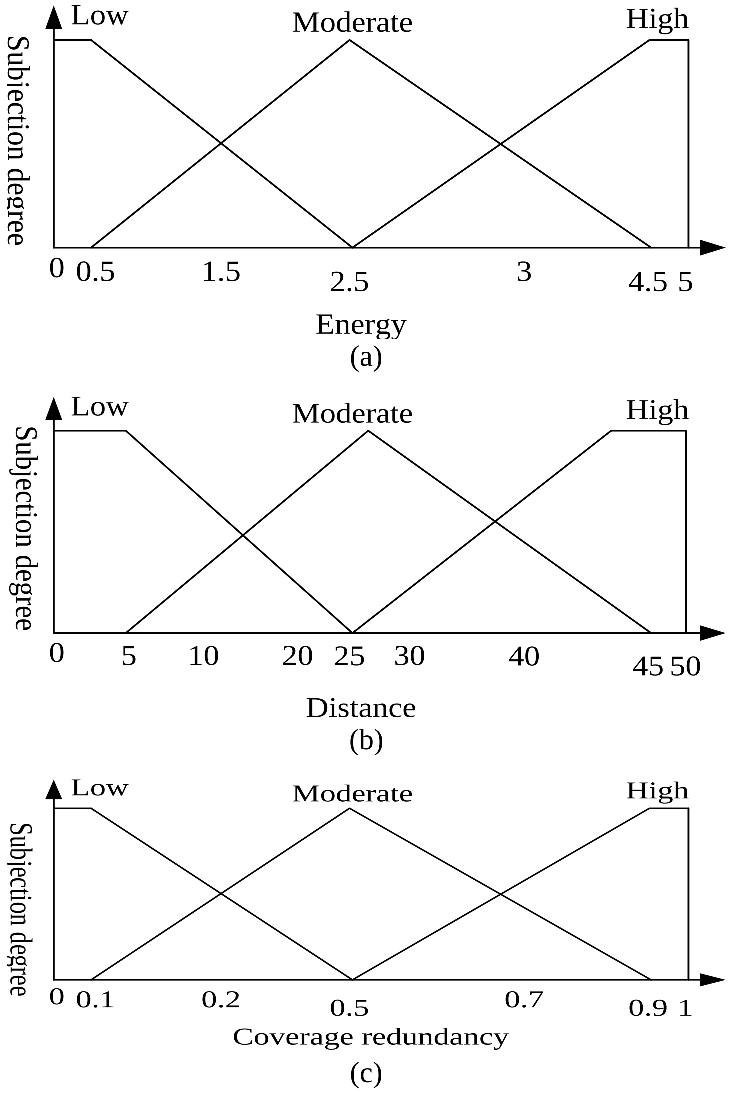
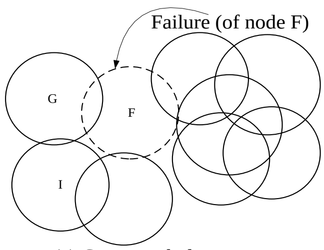


Figure 4. Subjection Degree of the Three Inputs

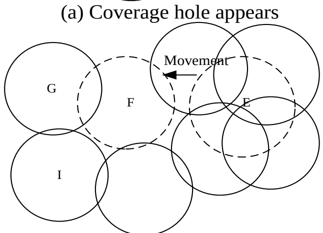
Sequence the neighbor nodes by virtue of the three information items, and the sequencing basis is shown in Table 3. As is shown in Table 1, the smaller the serial number is, the greater the probability of being selected will be. After selecting the node, corresponding movement will be conducted; then the selected node will move with the FLS1 algorithm as the basis, as is shown in Figure 5. Figure 5 sets out to describe the whole process of hole repairing by the mobile node. Aimed at failure of node F, node E, according to the FLS2 algorithm, is selected as the mobile node to repair the coverage hole [11-13] caused by failure of node F.

Table 1. Rule Base of FLS2

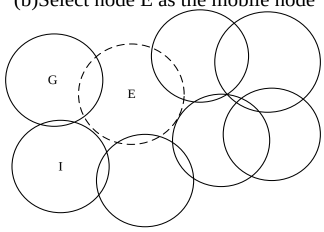
rule	Input variables			
	Energy	Distance	Coverage redundancy	Probability of being selected
1	High	High	High	VHigh
2	High	High	Medium	VHigh
3	High	High	Low	High
4	High	Medium	High	High
5	High	Medium	Medium	High
6	High	Medium	Low	Medium
7	High	Low	High	Medium
8	High	Low	Medium	Medium
9	High	Low	Low	Low
10	Medium	High	High	Medium
11	Medium	High	High	Low
12	Medium	High	Low	Low
13	Medium	Medium	High	Medium
14	Medium	Medium	Medium	Medium
15	Medium	Medium	Low	Low
16	Medium	Low	High	Medium
17	Medium	Low	Medium	Low
18	Medium	Low	Low	VLow
19	Low	High	High	High
20	Low	High	Medium	Medium
21	Low	High	Low	Low
22	Low	Medium	High	Medium
23	Low	Medium	Medium	Low
24	Low	Medium	Low	VLow
25	Low	Low	High	Low
26	Low	Low	Medium	VLow
27	Low	Low	Low	VLow



(a) Coverage hole appears



(b)Select node E as the mobile node



(c)After hole repairing

Figure 5. Schematic Diagram for the Process of Hole Repairing by Mobile Node

4. Communication Module Design

4.1. Realization of Server-side Communication Module

For server side, on the one hand, it needs to receive environmental data frequently uploaded by environment collection equipment; on the other hand, it needs to handle data request of mobile phone client side. Faced with the two kinds of different communication requests, server-side adopts two kinds of different communication methods. (1) Adopt non-blocking communication method based on Socket for communication among environment collection equipment. (2) Adopt Http Client method based on HTPP for communication among mobile phone client sides.

Socket communication method is a blocking-type. After server side monitors Socket connection of client side, it will launch a new thread to conduct data interaction; each Thread will only dispose one Socket connection; only after client side breaks connection automatically, server side will release resource. In the environment of Internet of Things, a large number of sensors equipment will connect with system; adopting blocking-type communication will only lead to reduction of server performance. Java NIO non-blocking communication after JDK1.4 (Java Development Kit) can meet communication requirement of high concurrency. Java NIO realizes non-blocking communication by three important components of Buffer, Channel and Selector. Herein, Buffer is used for store all kinds of format data temporarily. Channel is used to read and write data that is sent from client side to server side. Selector is used to manage Channel and dispatch a Thread to dispose many Channels.

System server side firstly sets non-blocking passage by realization type Server Socket Channel of Channel; creates Socket monitoring and binds Channel in Selector manager by register method. When client side connects with server, Selector manager will select a Socket Channel example object treatment and interaction with client side by Selector manager when client side connects with server. Release the Socket Channel after closure of interaction.

There are methods of Socket and Http Client in network communication of Android system. Client side can better integrate with Spring MVC framework in server by adopting Http Client method. Mobile phone client side can send POST request to server by Http Client. Server will encapsulate requested data into JSON format and return it to mobile phone client side.

4.2. Realization of Client-side Equipment Management Module

To reduce use complexity of system, system will add environment collection equipment by adopting the method of scanning 2-dimensional code. 2-dimensional code is a kind of new information storage and transmission technology. Express binary data in the method of black and white pattern according to specific coding rule and in the method of black and white matrix pattern. Inclusive information [11] can be obtained after equipment scanning it. At present, the most extensive 2-dimensional code is QR code (Quick Response Code). This kind of 2-dimensional code can put in 1817 Chinese characters to the maximum. Initialization parameters of several sensors of a set of equipment can be stored by the method of 2-dimensional code. Users can obtain initialization information of equipment after scanning the 2-dimensional code. The equipment will be added to system.

In system, increase of equipment is realized by adding Device Activity type. Third-party library file qrcode. jar will be introduced to recognize 2-dimensional code. This type firstly invokes mobile phone camera to capture image of 2-dimensional code and stores it as Buffered mage object; transmit Buffered Image to decode method of qrcode type as parameters. After analysis of 2-dimensional code by this method, return inclusive information in2-dimensional code in the method of character string. After system obtains initialization information of equipment, users are allowed to modify initialization information according to actual condition. Users can add new equipment to system after kicking storage button.

5. Experiment and Analysis

5.1.Network Service life and Energy Consumption

Firstly, analyze energy consumption and invalid cluster-head number in scheme of the paper. Result is shown in Figure 6. In the condition of same round, energy consumption put forward in DEAOP scheme of the paper is less than CPCP-ea and EEUC scheme. It is mainly because that CPCP-ea protocol does not consider invalid condition of cluster head and energy utilization rate is low. When cluster head is invalid, it still transmits data to cluster head when cluster head is invalid. Therefore, energy is wasted. However, EEUC protocol is superior to CPCP-ea protocol. It is because that EEUC protocol considers invalid condition of cluster head CH. Besides, Figure 6 also describes invalid number of cluster head CH of several protocols. It is shown in data that invalid cluster head CHs proposed in protocol of the paper is obviously less than CPCP-ea and EEUC.

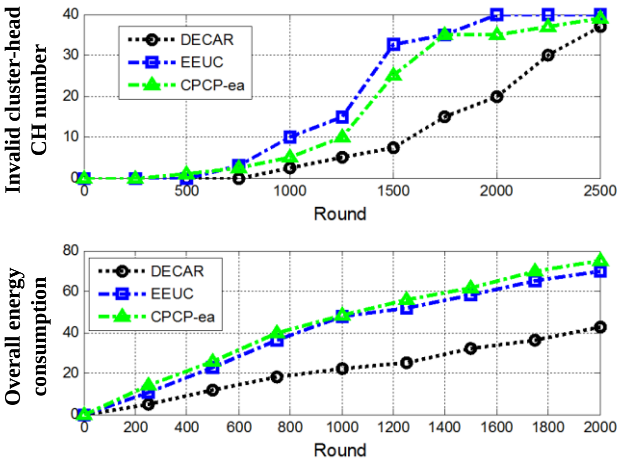


Figure 6. Energy Consumption

Table 2. Relationship between Energy Consumption and Running Round Number

Test	Energy consumption 50%			Running 1000 rounds		
	CPCP-ea	EEUC	DECAR	CPCP-ea	EEUC	DECAR
1	475	476	1038	48.89	47.35	23.49
2	477	474	1088	48.43	46.95	21.87
3	475	476	1109	48.48	47.76	21.23
4	479	484	1092	48.60	47.76	21.23
5	475	484	1123	48.99	47.01	20.24
6	478	480	1058	48.69	47.30	22.89
7	474	473	1076	48.94	47.48	22.71
8	482	472	1060	48.66	47.83	22.61
9	469	483	1097	48.81	47.30	21.48
10	475	478	1116	48.60	47.38	21.03

Table 2 lists part of experience data. From Table 2, it can be known that protocol put forward in the paper has run for 1082 rounds when energy is consumed nearly 50%. CPCP-ea and EEUC has respectively run for 477 rounds and 478 rounds. It can be known from energy consumption data that energy consumption utilization rate of protocol in the paper has been promoted for 127.0% and 126.6% compared with that of CPCP-ea and EEUC. For example, when it runs for 1000 rounds, protocol put forward in the paper only consumes 22.0J energy. However, CPCP-ea protocol and EEUC protocol respectively has consumed 48.6J and 47.5J.

Table 3. Active Nodes Number and Rounds Number of the First Invalid Nodes

Test	Active nodes number (running for 2000 rounds)			Network service life		
	CPCP-ea	EEUC	DECAR	CPCP-ea	EEUC	DECAR
1	1	9	25	754	736	1274
2	1	6	15	755	716	1228
3	1	9	19	754	739	1265
4	1	5	18	775	758	1303
5	2	6	21	783	676	1231
6	1	10	21	761	731	1328
7	1	5	16	782	696	1148
8	1	8	25	760	759	1329
9	1	4	22	764	723	1320
10	1	9	21	772	769	856

Table 3 lists two items of data in experience: 1) after running for 2000 rounds, active nodes number; 2) total running rounds of the first invalid nodes, namely network service life. It can be known from Table 3 that occurrence time of protocol put forward in the paper on the first invalid nodes has improved for 66.9% compared with CPCP-ea protocol and for 71.9% compared with EEUC protocol. These performance promotions owe to residual energy of protocol utilization node energy and selective cluster head of cover overlapping ratio put forward in the paper.

5.2. Contrast Experiment of Ability Consumption

The purpose to put forward RCH-FL algorithm is to move position of sensor nodes and to realize the maximal region coverage with the minimal energy consumption. To analyze consumed energy of sensor nodes in the moving process, establish the following scene: sensor nodes distribute randomly for 8 times. After each random deployment, part of sensor nodes will move and reach the same coverage rate. Analyze average energy consumed by sensor nodes in the movement process under the environment. Results are shown in Figure 7.

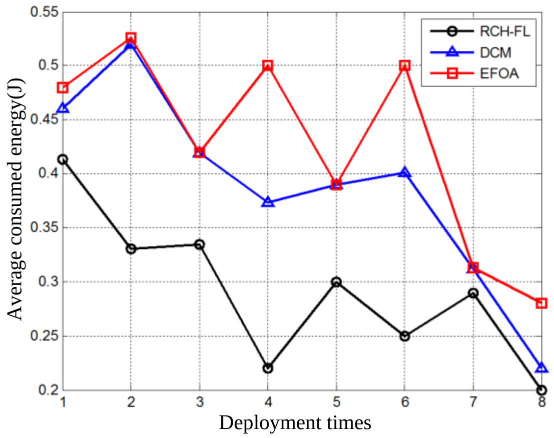


Figure 7. Average Energy Consumption

It can be known from Figure 7 that average energy consumption of DEAOP algorithm is lower than DCM and EFOA. The reason is that RCH-FL algorithm selects mobile nodes correctly. Mobile nodes move accurately to destination according to local node density and Euclidean distance information. Energy consumption of EFOA is the highest because it adopts random movement strategy, movement blindness exists and energy consumption is increased. Besides, DCM scheme energy utilization rate is lower than RCH-FL algorithm. Because DCM searches movement position by GPS and running GPS and receiving signal all need energy, so energy consumption is increased.

5.3. Contrast Experiment of Coverage Rate

Figure 8 describes change curve of coverage rate with the number of sensor nodes; coverage rate will rise with the increase of the number of sensor nodes. Herein, coverage rate of DEAOP algorithm is the highest. Average coverage rate reaches 99.5%; however, DCM is 90% and EFOA is only 82%. Contrast results of coverage rate are shown as Figure 8.

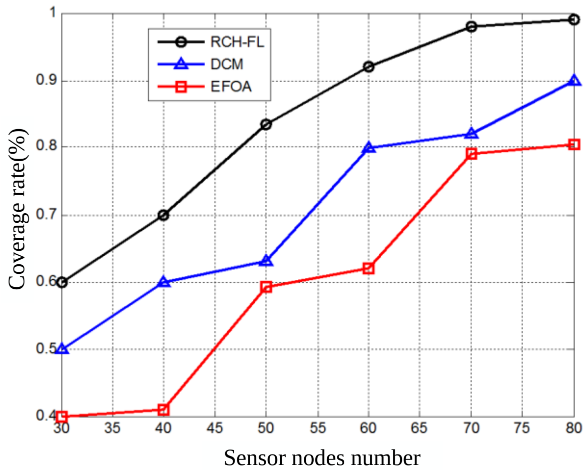


Figure 8.Change Curve of Coverage Rate with Sensor nodes Number

6. Conclusion

Because uneven distribution of sensor nodes, exhausted energy and faults, coverage hole always exists in WSNs. On the one hand, coverage hole leads to blind spot in sensor nodes when collecting data; on the other hand, data transmission will break off and therefore, performance of the whole network will be influenced. Therefore, the paper puts forward RCH-FL algorithm based on fuzzy logic coverage hole repair. RCH-FL algorithm quotes the concept of mobile nodes repairing hollow. Select the optimal mobile nodes by making use of fuzzy logic and combining with information of three aspects of energy of sensor nodes, distance from hollow and coverage redundancy. Subsequently, calculate position of mobile target by making use of nodes density and regional average Euclidean distance. Simulated results show that RCH-FL algorithm can repair coverage hole effectively.

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