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Analysis and Comparison of Relay Node Selection Algorithm of Cooperative Communication

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Abstract: The decline of wireless channel is a key factor that hinders the reliability and validity of wireless communication. The emergence of multi-input multi-output system can solve this problem effectively. However, the implementation is extremely difficult because of the impact caused by terminals. Cooperative communication improves diversity gain by using the traveling carriage of single antenna to share other users' antennas in multi-user environment. However, relay node selection of cooperative communication is a primary key problem to be solved. This study, presented relay node selection algorithm evaluation indicators according to the reliability and validity of communication and classified the existing relay node selection algorithms according to the indicators. The study analyzed and compared several common algorithms, finding out their advantages and disadvantages, providing a clear direction for relay node selection of cooperative communication.

Key words: Cooperative communication, relay node, terminals, comparison, multi-input multi-output system

INTRODUCTION

The demand for the quality of wireless communication has become increasingly high with the development of wireless communication. How to further expand channel capacity and improve communication quality and efficiency are issues needed to be focus on. The decline of wireless channel is a key factor that hinders the reliability and validity of wireless communication.

To solve this problem, the advantages of multiple-input multiple-output system have been accepted widely. Because of the impact of node size and energy, the implementation of this technology becomes difficult. Cooperative communication technology compensates for these shortcomings effectively which can make use of the multilateral transmission characteristic of wireless waves to make each node in wireless network cooperating to form a virtual multi-antenna, attaining space diversity gain (Mei and Li, 2009).

Cooperative communication faces the relay node selection problem and relay node selection is directly related to the effectiveness of cooperative communication. Relay node selection is completed through certain algorithms, so the evaluation of relay node selection algorithms is a problem that the author concerns. According to the evaluation indicators, the author classified the existing relay node selection algorithms and then analyzed the advantages and disadvantages of these algorithms, aiming to provide a clear direction for relay node selection of cooperative communication.

THE EVALUATION INDICATOR OF RELAY NODE SELECTION ALGORITHM

The algorithm complexity and effect: The algorithm complexity includes time complexity and space complexity. Time complexity of algorithm is the length of the execution time of algorithm. Space complexity of algorithm is the necessary storage space of algorithm during execution. If an algorithm' execution time is too long and needs large storage space, the algorithm complexity is high which is clearly inconsistent with the requirements of mobile communications. Cooperative communication improves communication quality by network sharing. It needs to add other elements involved in the design of algorithm. This is bound to lead to the increase of algorithm complexity and the final communication effect is unknown. How to control the algorithm complexity and improve the performance of system effectively is an important evaluation indicator for relay node selection (Yan *et al*., 2010).

Adaptability and self-correction of algorithm: Ensuring reliable and correct transmission of information is the key

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of wireless communication. Multipath wireless channel and varied nodes would affect channel transmission. This requires relay node selection algorithm should have good adaptability and self-correction. Algorithm should be able to adapt to the complicated environment of wireless channel and should be intelligent enough to correct common errors and reduce signal loss. So whether relay node selection algorithm is adaptive and self-corrective is an important indicator to measure the performance of cooperative communication (Yan *et al*., 2010).

Communication loss: There be communication loss for cooperative communication system as information interaction and transmission need energy consumption between nodes. Reducing the loss as much as possible is a goal for cooperative communication. Only when cooperative gain is larger than system loss, such cooperation is effective. Thus, relay node selection algorithm needs to consider the problem of communication loss which affects the quality of communication system to some extent (Himsoon *et al*., 2007).

Interference and competition: Network application environment determines whether the network can transmit information reliably. Common wireless communication includes network supported by fixed facilities and network without fixed facilities. For the network without fixed facilities, interference and competition will occur between nodes without unified management which is bound to affect the communication performance. Thus, the design of relay node selection algorithm should consider the interference and competition between nodes.

Interrupt rate and bit error rate: Interrupt rate and bit error rate are core elements measuring communication performance. Interrupt rate is an assurance of transmission reliability and bit error rate is an assurance of information effectiveness. To attain good communication performance, it is necessary to reduce interrupt rate and error rate. Thus, the design of relay node selection algorithm should consider these two elements.

CLASSIFICATION OF RELAY NODE SELECTION ALGORITHMS

Currently, there has been a lot of relay node selection algorithms of cooperative communication. The design of these algorithms are based on the evaluation indicators. These relay node selection algorithms are divided into four categories according to the evaluation indicator.

Classified by numbers and attributes of relay node: Relay node selection algorithm is divided into single-node algorithm and multi-node algorithm according to node numbers. Single-node algorithm is fast, convenient and less power consumption. However, single-node algorithm is unbearable when signal declines severely. Multi-node algorithm can take the initiative to choose the best cooperative node. Relay node selection algorithm is divided into fixed node algorithm and mobile node algorithm according to node attributes. Fixed node selection algorithm is relatively simple and can reduce energy by base stations communications. Mobile node selection algorithm needs to consider the relative distance of mobile station and base station.

Classified by cooperative approaches: The cooperative approach is an important part of cooperative communication system. Different cooperative approaches require different relay node selection algorithms. For instance, amplifying forward and decoding forward are two different cooperative ways and their relay node selection algorithms are different. For amplifying forward cooperative way, cooperative nodes do not need to do any processing about source node and all nodes can transmit information, but for decoding forward cooperative way, cooperative nodes need to decode correctly to transmit information.

Classified by the perspective of energy considered: The execution modes of algorithm are divided into central and distributed mode. Central algorithm has a central node which is responsible for management, including accepting and transmitting information. Distributed algorithm does not have a central node and nodes decide whether to participate in cooperation by themselves. Energy consumption of these two methods is different. Central algorithm is generally equipped with energy support and even may be multi-antenna which has strong information processing ability. Distributed algorithm must rely on its own energy and the information processing ability is weak.

Classified by channel state information: Algorithms are classified by channel real-time state mainly because channel decline. This type of algorithm is mainly to transmit a request or send command between source node and destination node and measure channel when sending a command packet. It obtains channel measurement parameters by monitoring and calculating. When all relay nodes finished calculating parameters, the system starts the timer to determine node situation and sends notification to each node. Finally, the system will find a good channel and finish a relay selection.

ANALYSIS AND COMPARISON OF COMMON RELAY NODE SELECTION ALGORITHMS

Relay node selection algorithm based on cooperative gain: Yan *et al.* (2007) proposed a relay node selection algorithm based on single node. Improving gain by this algorithm is limited and it is unable to obtain multiple node cooperative gain. Gao *et al.* (2008) proposed a multiple-node relay selection algorithm based on cooperative gain aiming at these shortcomings. This literature analyzed the relationship between relay node numbers and system performance and provided algorithms on choosing the best node number and improving system performance.

The basic principle is: Firstly, set initial channel capacity and forward repeater collection. Secondly, choose the best relay node according to relay node selection formula of channel gain maximum. Finally, calculate candidate relay collection value. If this value is greater than or equal to the search threshold, then end it, otherwise calculate and compare again. If the gain is greater than the predetermined value, then join nodes, otherwise removes nodes.

The algorithm is described simply as: when adding one relay node can not improve system performance significantly, don't use this relay node to transmit data. In this algorithm, gain threshold value of channel capacity is an important parameter. If the value is too large, there would be little selected relay nodes and cannot obtain obvious diversity gain. If the value is too small, there would be many selected relay nodes and the algorithm complexity increases which is not conducive to synchronous implementation. In order to avoid selecting excessive relay nodes causing resources cracking, the algorithm limits the maximum number of relay nodes (Gao *et al*., 2008).

Relay node selection algorithm based on coding cooperative approach: Relay method of cooperative communication includes amplifying forward, decoding forward, encoding cooperative. The following describes a common relay node selection algorithm based on encoding cooperative way. Encoding cooperation is an approach which combined channel coding with cooperative diversity. It is achieved by sending different parts of each user codeword in two independent declining channels. The basic idea is that each user must transmit increasing redundant information for cooperative partner. However, when cooperation can not be achieved, users can convert to non-cooperative state automatically.

Take two users' cooperation as an example to illustrate the implementation procedure of encoding cooperation. Firstly, users block source data, codeword compiled by each user's data is divided into two parts with N_1 bits and N_2 bits. Each user's data transmission cycle is divided into time slice used to transmit N_1 and N_2 bits of information, respectively which is called a frame. In the first frame, two users transmit N_1 bits, respectively and decode their partner' data. If decoding successfully, two users transmit N_2 bits codeword of their partner in the second frame. In the second frame, two users are independent with each other and they can not determine whether they decode successfully or not. In this situation, it will have four situations between two users' decoding success and failure. When the channel is asymmetric, system communication performance is affected significantly (Dong and Zheng, 2007). At this time, space-time cooperative approach can solve this problem. This will increase the complexity of algorithm undoubtedly.

Relay node selection algorithm based on energy consideration: Relay nodes selection is closely related with node transmission power in addition to channel quality and geographic issues. In order to optimize communication system performance, user's power allocation is also a key factor in addition to considering cooperative approach which determines energy gain of cooperative users. In wireless communication system, changing location of mobile station causes various energy consumption. It may reduces users' energy consumption by power allocation which can extend network life cycle and improve communication performance.

Mahinthan *et al.* (2008) proposed a relay node selection algorithm based on optimal power allocation. In cooperative approach of amplification and decoding, it can minimize system power consumption by grouping relay nodes and setting appropriate power level for each group which would reduce users' battery power consumption finally. The algorithm includes two steps, firstly determine the location of relay node and then conduct power allocation.

Qin *et al.* (2011) proposed a node selection algorithm based on dynamic multi-relay decode forwarding. The author gave a detailed analysis for this algorithm. The basic principle is: extending the idea of single-node relay selection to multi-node relay selection, considering the channel state and residual energy information of nodes, choosing relay collection which extended network lifetime furthest so that channel and energy can be shared after relay selection and dynamic power allocation within cooperative nodes. Practices have confirmed that the algorithm can improve network lifetime and system channel capacity effectively.

The algorithm design consists of the following steps: Firstly, each relay node calculates channel function with the minimum standards or harmonic mean criteria according to two-hop channel information. Secondly, each relay node calculates the ratio of residual energy in the total energy of each node after emission according to its current residual energy. Thirdly, setting node channel function weights and calculating the channel energy weighting function of all nodes.

Multi-node selection of decoding cooperation can be achieved by the following methods. Firstly, arrange relay nodes in descending order; secondly, compare speed rate, selecting the first relay node and comparing speed rate of the first hop and the second hop. If the former is smaller, then select to end it. If the former is larger, then select the second relay node. Calculate the summation of the second hop speed rate of two relay nodes and compare the summation with the minimum of the first hop speed rate of two relay nodes. If the result match the first hop speed rate and select to end it, otherwise continue to select the next node until the summation of the second hop speed rate matches the first hop speed rate (Qin *et al*., 2011). This algorithm may lose some of the total capacity, but it has advantages in using surplus energy and reducing the complexity of algorithm.

Relay node selection algorithm based on real-time channel state: Opportunity relay is a relay node selection algorithm based on real-time channel state. The basic principle can be expressed like this: the best relay node in KT time is i and the best relay node in (K+1) T time is j. $a_{s,i}$ and $a_{i,d}$ stand for real-time channel information of source node to relay node and relay node to destination node, respectively. In the same channel state condition, each node can calculate channel parameters h_i and node i with the largest h_i is the relay node selected. h_i can be calculated in two ways. After receipting the packet information, each relay node will trigger the timer T_i. Thus, timer of the best relay selection is timeout at the first. The best relay will send a signal flag to other nodes to show the best relay identity, at the same time, other nodes exit this competition.

As is shown in Fig. 1, when two or more timer trigger time is near, calculate the conflict time.

In Fig. 1, b represents the best relay node while j is another relay node, n_i is the propagation delay of node i and destination node, r is the propagation delay of two relay nodes, d_s is the transceiver conversion time, d_1 is the transmission time of sign package and d_2 is the time of broadcasting information. When hiding the relay, in the worst case, the conflict time $c = |n_b-n_j|_{max}+2\times d_s+d_1+2\times n_{max}$ and the average time to select the best relay $T = n_b+T_b+d_s+d_1+n_b$ ($+d_s+d_2+n_j$, hidden relay).

Shorten conflict time can be achieved by analysis and calculation which can reduce collision probability. Literature 13 also proposed an improved opportunity relay algorithm. The algorithm is realized by the following steps:

Step 1: Set threshold to eliminate the nodes of which channel state is poor

Step 2: Start the timer T_s after the source node has sent information, when T_i is timeout, relay node b send the d_1 sign package and short time news to source node and destination node, respectively and start the confirm timer T_{ACK}

Step 3: Destination node sent busy signal to all the relay nodes after receiving and suggest the hidden relay nodes that are not timeout cancel timing

Step 4: If source node received the sign package from relay node b within T_s, send waiting signal A to relay node b and the destination node while confirming the success; if the confirmation is

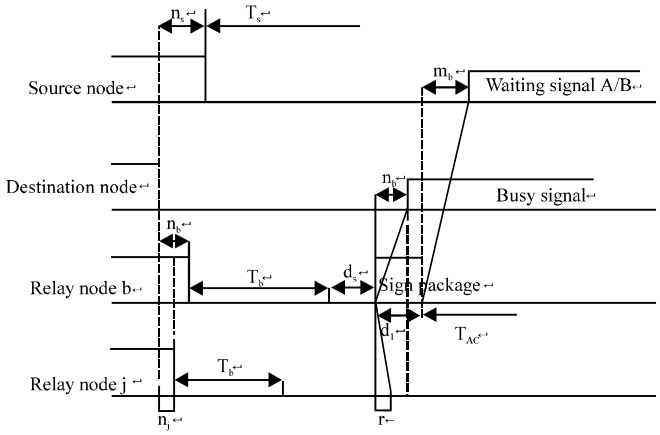

Fig. 1: Algorithm conflict model

Table 1: Comparing advantages and disadvantages of algorithms

Algorithm type	Advantages	Disadvantages
Relay node selection algorithm based on cooperative gain	Real-time dynamically determine the number of nodes, immediately removing redundant	No obvious gain when node numbers are little and algorithm complexity increased with much nodes
Relay node selection algorithm based on coding approach	Codeword block transmission, independent-channel transmission, anti-jamming	Space-time cooperative approach adds the cooperative complexity of algorithm when channel is asymmetric
Based on energy consideration	Save energy, good adaptability	Complexity of algorithm is high
Relay node selection algorithm based on real-time channel state	Good adaptability, the process changing conditions flexibly	Difficult to select at the same channel state

unsuccessful or timeout, send waiting signal B only to the destination node

Step 5: If relay node b received the waiting signal A before T_{ACK} timeout, it means the best relay is confirmed ; if not, then give up the best relay competition (Ren *et al*., 2010)

The improved algorithm model is also shown in Fig. 1. The conflict time $c = \max \{|n_b-n_j|+d_s+r, |n_b-n_j|+d_s+n_b\}$. Compared with the original algorithm, d_s and d_1 are microsecond level, so the conflict time reduction is obvious. The best relay select time $T = n_b+T_b+ds+d_1+m_b$ which is shorter than the original algorithm.

Analysis and comparison of algorithms: The following summarized their advantages and disadvantages, as shown in Table 1.

CONCLUSION

This study mainly proposed some evaluation indicators of cooperative communication relay node selection algorithms and classified cooperative communication relay node selection algorithms according to the evaluation indicators and analyzed some common relay node selection algorithms deeply and compared their advantages and disadvantages. This will provide a good reference for cooperative communications relay node selection. In fact, there is no perfect algorithm. You need to take all factors into consideration in practical application and select the most appropriate algorithm under the premise of ensuring optimal network performance. All algorithms serve the reliability and validity of cooperative communication ultimately.

The author only gave theoretical analysis and comparison of relay node selection algorithm. And the author will study the rationality of algorithms for further research, such as using quantitative methods to analyze the reliability and validity of algorithms in cooperative communication. Cooperative communications relay node selection algorithm is the core of cooperative communication system performance research. The author believed that deep analysis and research of algorithm will bring a bright future for development of cooperative communication technology.

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