

Review

A Review of Relay Assignment Problem in the Cooperative Wireless Sensor Networks

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Abstract: The relay selection is a promising approach of maximizing the diversity gain achieved in the cooperative wireless sensor networks. In the cooperative networks, the proper selection of relay node is a challenging task. The proper selection of relay nodes not only improves the source–destination performance, but also maximizes the overall system performance. There are many factors involved in designing a relay selection algorithm. The different relay selection algorithms have different focus, criteria, objective, mechanism, and performance issues. In this article, several relay assignment algorithms have been analyzed to show the effectiveness of channel capacity, power allocation, coverage expansion and interference mitigation in term of proper relay selection schemes. Moreover, this paper discusses some relay selection schemes, their challenging issues, limitations, performance criteria, and mechanisms. This article also highlights the significant design issues of relay selection methods and compares them that are appropriate in the cooperative wireless sensor networks.

Keywords: cooperative wireless sensor networks; multi-classification; relay assignment; af-df relay

1. Introduction

In the cooperative wireless sensor networks, the data rate of the wireless channel is improved selecting the best relay node in the networks. The cooperative wireless networks achieve the spatial diversity by deploying the antenna on another cooperative node without requiring multiple transceiver antennas per terminal, which allows the surrounding terminals to collaborate, working as a virtual MIMO antenna array [1]. The major advantage of this diversity technique is that different paths are likely to fade independently, which is effective to cope wireless fading channel [2].

There are two types of transmission modes in cooperative wireless transmission, namely, Amplify and Forward (AF) and Decode and Forward (DF) modes [3,4]. The AF techniques amplify the signal received by the relay and forward the signal to the destination node. In DF method, the relay node receives and decodes the source signal at first and then transmits to the receiver. Generally, the AF and DF modes consist of two phases as shown in Figure 1. In the first phase, the source node sends the signal to the destination nodes and all potential relay nodes. In the second phase, the relay nodes forward the overheard signal to the destination. One of the major drawback of the AF mode is that the relay node amplifies the noise of the signal with the data and the destination node receives two independently faded versions of signal. On the other sides, in DF method, the relay nodes, which have error correcting technique, require much computing power. Another method is coded cooperation in which the received data bits are broken down into two parts. One part is transmitted by the user and the other part is transmitted by the partner. The cooperative wireless communication proceeds by frame fashion. In the first time slot of Figure 1, the source node, s , sends data to destination node, d . Due to broadcast nature, the relay node, r , hears this transmission, uses the second time slot, r , forwards the data to d using either AF or DF mode.

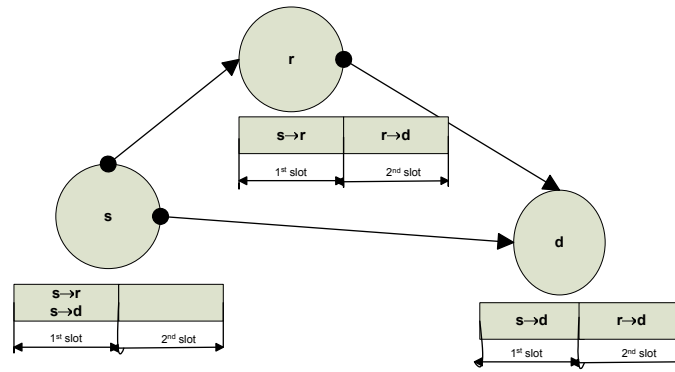


Figure 1. Cooperative transmission phases.

The Relay Node Assignment Problem

The cooperative wireless communication is illustrated by a three-node diagram as shown in Figure 1. In this diagram, sensor s , d , and r work as source, destination, and relay node, respectively. The achievable data rate under AF and DF modes are

$$C_{AF}(s, r, d) = W \cdot I_{AF}(SNR_{sd}, SNR_{sr}, SNR_{rd}) \quad (1)$$

where

$$I_{AF}(SNR_{sd}, SNR_{sr}, SNR_{rd}) = \frac{1}{2} \log_2(1 + SNR_{sd}) + \frac{SNR_{sr} \cdot SNR_{rd}}{SNR_{sr} + SNR_{rd} + 1} \quad (2)$$

The capacity of DF is given by

$$C_{DF}(s, r, d) = W \cdot I_{DF}(SNR_{sd}, SNR_{sr}, SNR_{rd}) \quad (3)$$

where

$$I_{DF}(SNR_{sd}, SNR_{sr}, SNR_{rd}) = \frac{1}{2} \min\{\log_2(1 + SNR_{sr}), \log_2(1 + SNR_{sd} + SNR_{rd})\} \quad (4)$$

In cooperative communication, the sender node, s , transmits to the receiver node, d , using direct transmission path. Thus, the capacity from s to d is calculated as

$$C_D(s, d) = W \cdot \log_2(1 + SNR_{sd}). \quad (5)$$

Comparing the capacity of amplify-forward C_{AF} (or decode-forward C_{DF}) to direct transmission C_D , it is difficult to decide that cooperative communication is always better than direct transmission. Therefore, an improper relay node selection could make the capacity under cooperative communications less than direct transmissions. However, the selection and assignment of relay nodes play a vital role in achieving the transmission rate and channel capacity. The important issue of multiuser cooperative networks is how partners or relay nodes are selected. Therefore, recent researches in the cooperative wireless networks focus on appropriate relay assignment algorithms to improve network performance.

In this article, an overview of some relay selection schemes, their challenging issues, performance criteria, and mechanisms are discussed. This article also highlights the design issues of relay selection methods and compares them.

2. The Key Factors and Challenging Issues to Design Relay Selection Method

Different protocols and algorithms are applied to wireless sensor networks to decide the appropriate partners or relays node. The challenging issues in selecting the relay nodes should address the following factors.

- Share and manage the channel state information between source and relay nodes in a timely and distributed manner to avoid delay and collision.
- In multiuser scenario, an efficient scheduling technique needs to be addressed when one relay node serves multiple sources and destinations, and also needs to develop a schema that treats all users fairly.
- Management of resource and multiple access protocols become an issue when cooperative methods allow multiple partners.
- Another challenging issue is to design the power control mechanisms for the system like ad hoc sensor networks where the sensor nodes have limited battery power. The energy efficiency and power consumption become an challenging issue to select relay protocol in order to save battery power.
- The interference produced by multiple relays require to be addressed and investigate its impact in the network performance.

To determine how and when partner nodes are selected and coordinated in multiuser networks is a great challenge and must address the following.

- Which methods are applied to determine users that cooperate?
- Is the relay method better than the direct transmission?
- What are the criteria to select a relay node which provides the maximum capacity?
- How is the transmission power distributed between the source and relay nodes?

To address the above issues, the relay selection method should consider the key factors that are shown in Figure 2.

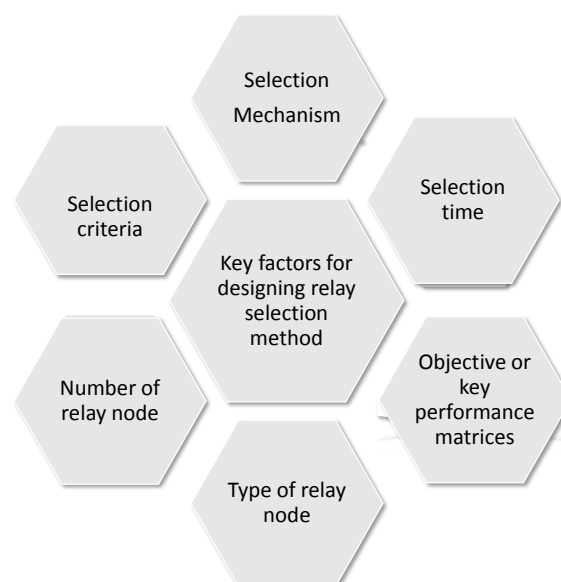


Figure 2. Key factors for designing relay selection method.

Relay selection strategies in cooperative networks also depend network conditions such as channel state information (CSI), distance from source to destination node, available bandwidth, and signal-to-noise ratio. In multiuser scenario, relay selection mechanisms are divided into two categories.

- **Centralized mechanism:** uses a central node such as base station or centralized table, which runs centralized algorithms. These mechanisms focus on solving complicated optimization problems by assuming complete channel state information of the networks [5]. Relays can be selected to optimize a given performance criteria such as maximize the channel capacity, average blocks error rate, or minimize the power consumption.
- **Distributed mechanism:** are used in ad hoc and wireless sensor networks. In a distributed method, the senders or receivers are able to choose the cooperative node at any given time [6].

Both relay selection mechanisms can be categorized by a number of relay nodes that an user communicates (i.e., how many relay nodes to be selected for the source node in the cooperative networks).

- **Single relay selection schemes:** In this schema, each source–destination pair has only one helper node. There are two distinction in this category. Only one relay can be assigned to one source and one relay can serve multiple sources simultaneously. The latter one needs better scheduling mechanisms.
- **Multiple relay selection schemes:** Each source–destination pair can be assisted by multiple helper nodes. In this mechanism, each source node has multiple helper nodes. It requires proper distribution of channel state information and better scheduling techniques [7].

The relay selection criteria will be

- **Cooperative:** selection procedure requires exchange of control information (RTS/CTS) among the nodes [1].
- **Opportunistic:** selection procedure uses local information of the network [8].

Selection time can be classified as

- **Group-based:** relay selection occurs before the transmission [9].
- **Proactive:** selection is performed during transmission [10,11].
- **On-demand:** selection occurs when needed [12].

In cooperative wireless network, the proper selection of relay node is a challenging task. The proper selection of relay nodes not only improves source–destination performance, but also improves an overall system performance. Many factors are involved when we design a relay selection method. Figure 3 highlights some factors, which required to be considered during the design of a relay selection protocol.

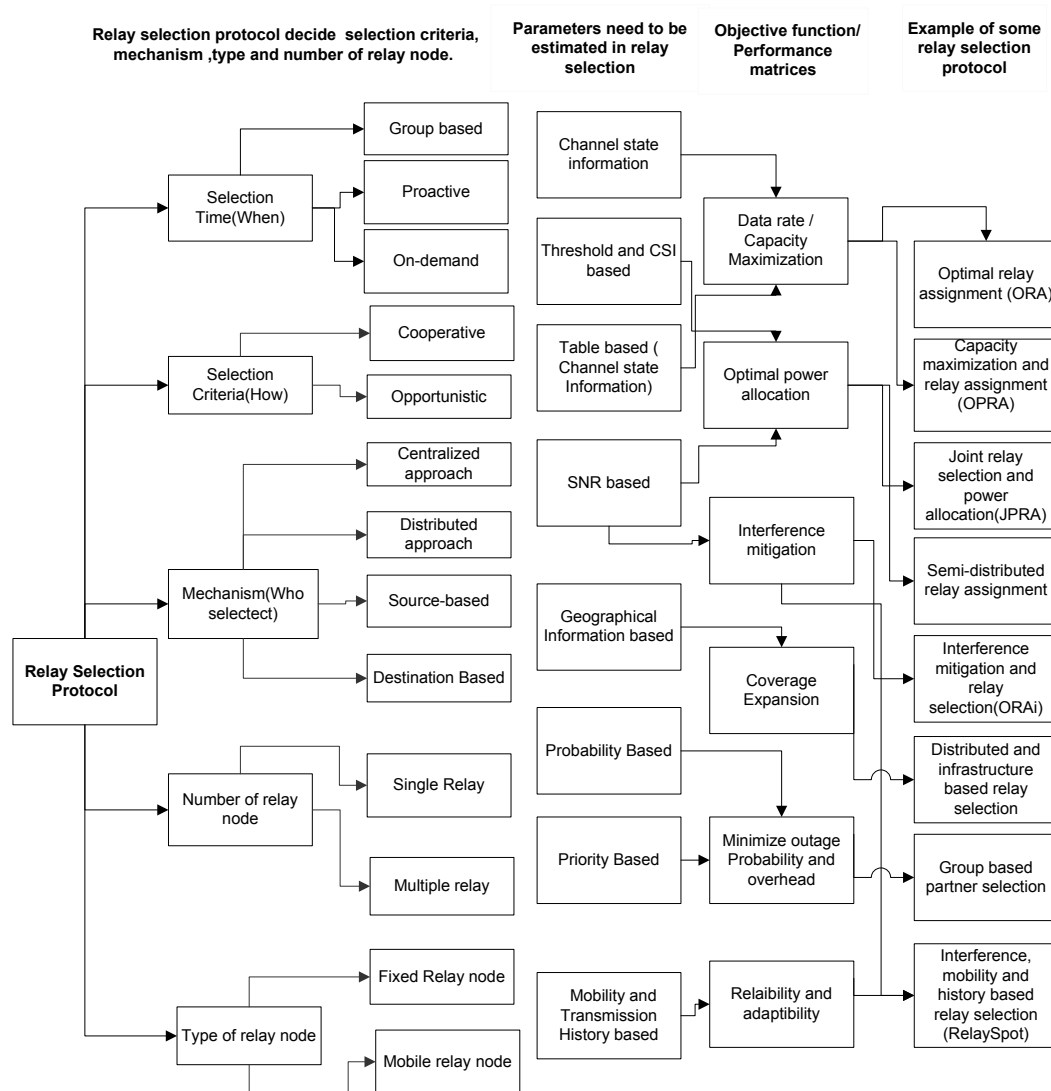


Figure 3. Relay selection scenarios.

Different relay selection schemes focus on different performance criteria. Some recent researches focus on following performance issues to select the appropriate relay nodes to the users.

- Capacity or data rate maximization and relay selection:** Capacity between source to destination pair (direct transmission path) and amplify forward, decode forward modes are calculated. Users select relay nodes based on the channel gain. There are several factors such as path loss, fading that are used to measure the channel gain between transmission pairs and relay nodes. The work done in [13,14] calculates the link capacity and propose an optimal relay assignment algorithms: ORA and OPRA, respectively.
- Energy efficient relay selection:** Relay node selection to minimize the power consumption and improve the energy efficiency of the networks. Cai et al. [15] propose a semi-distributed user relaying algorithm in AF wireless sensor networks. In this approach, users select relay nodes from a set of feasible relay nodes and at the same time maintain optimum power allocation. Similarly, the work done in [16] propose a joint relay assignment and power allocation (JRPA) algorithm for cooperative communication. The energy efficiency is one the main performance criteria to select the relay node in wireless sensor networks [17,18].
- Opportunist relay selection:** Opportunistic relay selection depends on instantaneous measurement of channel condition and does not require any topological information. In [19,20],

the authors propose a novel relay selection method that chooses the best relay node among M the available relays based on the signal strength measurements rather than distance.

- **Interference mitigation and relay selection:** Interference mitigation is the one of the key performance issues to design the relay selection method [10,21]. In cooperative network, multiple relay nodes cause interference to others. Interference associated with relay nodes is considered in this approach. Improper selection of relay node sometimes interact with others transmission rate. In [22], the authors measure the interference that is generated by relay nodes and update the selection process as well.
- **Relay selection and coverage expansion:** In cooperative communication, relay nodes help to expand the coverage area without increasing infrastructure. In [23], the authors consider the extension of coverage area using the relay selection method.
- **SNR-based relay selection:** The SNR between every transmission pair is estimated based on their available channel state information and a transmission pair selects relays calculating the optimal SNR value [24–26].
- **Resource allocation and relay selection:** The relay node selection and resource allocation are considered in [27], where the authors consider the utility maximization problem for the joint optimization of relay node selection and resource allocation.
- **Probability-based relay selection:** The work done in in [20] propose the best relay selection method using maximum a posteriori (MAP) detection algorithms. Similarly, the authors of [1] consider posterior probability-based relay selection method in wireless cooperative networks.
- **Relay selection using machine learning:** The work done in [28,29] apply machine learning techniques such as deep enforcement learning and artificial neural network to select the relay node in multi-hop wireless network.

3. Relay Selection Strategies in Cooperative Wireless Network

The work done in [2,30] consider different performance matrices. In this section, the taxonomy of relay assignment methods in cooperative wireless sensor networks is illustrated (in Figure 4) and discussed.

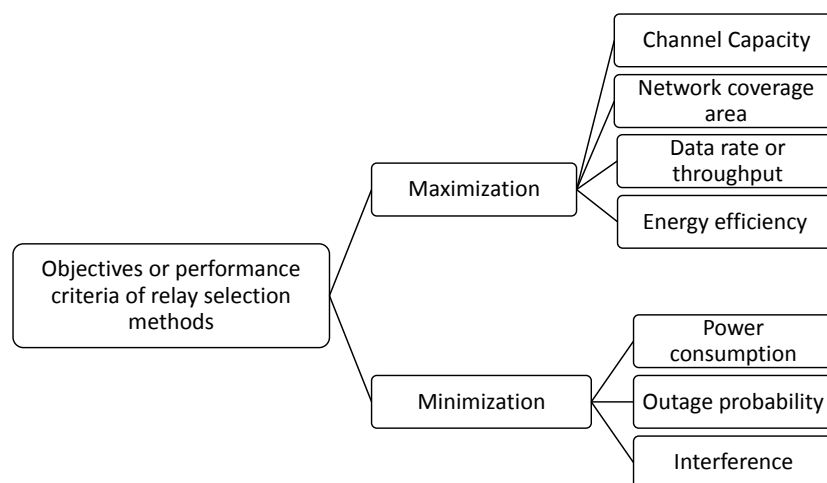


Figure 4. Taxonomy of relay selection methods in cooperative wireless sensor network.

3.1. Capacity Maximization and Relay Selection

The authors in [13,14] propose an optimal relay algorithm (ORA) for relay assignment, which considers ad hoc network with multiple source–destination pairs. The objective of ORA is to find an optimal relay node assignment for all the source–destination pairs such that channel capacity C_{min} is maximized, where C_{min} is the minimum capacity among all source nodes. $\mathcal{R}(s_i)$ denotes if

the relay node is assigned to s_i . In the case that s_i does not use a relay node, then $\mathcal{R}(s_i) = \emptyset$ and the capacity in the direct transmission will be $C_R(s_i, \emptyset) = C_D(s_i, d_i)$. In both case, the capacity of the transmission will be

$$C(s_i, \mathcal{R}(s_i)) \doteq \begin{cases} W.I_R(SNR_{s_i, d_i}, SNR_{s_i, \mathcal{R}(s_i)}, SNR_{\mathcal{R}(s_i), d_i}) \\ \text{if } \mathcal{R}(s_i) \neq \emptyset \\ W.\log_2(1 + SNR_{s_i, d_i}) \\ \text{if } \mathcal{R}(s_i) = \emptyset \end{cases} \quad (6)$$

The objective function of optimal relay assignment algorithm in [13] is given by

$$C_{min} = \arg \max \{ \min \{ C_R(s_i, \mathcal{R}(s_i)) : s_i \in \mathcal{N} \} \} \quad (7)$$

The relay node is assigned in ORA using the following steps.

- **Preprocessing/Initialization step:** ORA starts with a random relay allocation to each source–destination pairs. Each source has at most one relay node that follows one-to-one allocation problem.
- **Adjustment and Selection step:** Next step, ORA adjust the assignment during each iteration using objective function, identify source node which has lowest C_{min} . Then, select a new relay node to this source such that C_{min} can be increased.
- **Final Assignment:** If the selected relay node is already assigned to another source node, then require further node adjustment. Such adjustment is a recursive method that create a chain effect on a number of source nodes in the network. Finally, if a better adjustment is found then ORA moves to next iteration otherwise terminate. In the adjustment step, the ORA algorithm always maintain the objective function.

However, there are some limitations of the ORA as follows.

- In this approach, the source node and relay node should transmit at maximum power level to achieve maximum capacity under AF and DF mode which require to develop a efficient power control mechanism to improve performance.
- For interference mitigation, this approach assumes that infinite number of OFDMA orthogonal channels are available in the network which is impractical for networking point of view.
- Relay node assignment problem in a cooperative ad hoc network environment is addressed in this approach, where distributed cooperative protocol is needed for cooperation among users, which incurs additional overhead into the systems.
- Overhead associated with distributing the link state information in the network makes the implementation of this approach quite difficult.
- Applicable only when all users in ad hoc networks know about their channel gain and SNR values of their associated link. Otherwise, the adjustment and selection steps of the algorithms cannot select proper relay node.
- Scheduling techniques between transmission pairs and relay nodes is not addressed here.

On the other hand, the most closely related work was done by Dejun et al. [14]. They studied relay assignment problem in cooperative networks such that the total capacity of all pairs is maximized. The objective function of relay assignment problem is given by

$$C_{sum} = \sum_{s_i \in \mathcal{S}} C(s_i, \mathcal{R}(s_i)) \quad (8)$$

where $\mathcal{R}(s_i)$ denote if the relay node assigned to s_i .

Here, the same relay node can be assigned to multiple source node which is a another difference from the above approach [7]. In [14], $\mathcal{S}(r_j)$ denotes the set of source nodes to which r_j is assigned,

that is, $\mathcal{S}(r_j) = \{s_i | \mathcal{R}(s_i) = r_j\}$. In this approach, the relay node uses coded cooperation method, TDMA-based scheduling and serves each source node in a round-robin fashion. Each source node gets served every n_j frames, where $n_j = |\mathcal{S}(r_j)|$. Therefore, the average achievable capacity for each source node $s_i \in \mathcal{S}(r_j)$ is $\frac{C_R(s_i, \mathcal{R}(s_i), d_i)}{n_j}$. The overall capacity of this approach is

$$C(s_i, \mathcal{R}(s_i)) \doteq \begin{cases} \frac{C_R(s_i, \mathcal{R}(s_i))}{n_j} & \text{if } \mathcal{R}(s_i) \neq \phi \\ C_{DT}(s_i) & \text{if } \mathcal{R}(s_i) = \phi \end{cases} \quad (9)$$

In this approach, the relay node is assigned by optimal algorithm for relay assignment problem (RAP) using the following steps.

- **Initial set-up and graph construction:** A set of source nodes correspond to \mathcal{U} vertices and set of destination and relay nodes correspond to \mathcal{V} vertices and a set of edge \mathcal{E} are assigned where $(s_i, v) \in \mathcal{E}$ if $v = d_i$ or $v \in \mathcal{R}$. Using Equation (9), the initial capacity of all source, destination, and relay nodes are calculated, and then set the weight of all edges by $w(s_i, r_j) = C_R(s_i, r_j)$ for all $s_i \in \mathcal{U}, r_i \in \mathcal{R}$ and $w(s_i, d_i) = C_{DT}(s_i)$ for all $1 \leq i \leq n$.
- **Construct maximum weighted bipartite graph and find optimal relay node:** Apply maximum weighted bipartite matching algorithm to find a maximum weighted matching \mathcal{M}^* in graph $G = (\mathcal{U}, \mathcal{V}, w)$. For all $(s_i, v) \in \mathcal{M}^*$, the relay assignment of source node s_i is calculated by $\mathcal{R}(s_i) = v$ if $v \in \mathcal{R}$; otherwise, $\mathcal{R}(s_i) = \phi$, which means the capacity of direct transmission gives better option.

Some drawbacks of this approach are listed below.

- The running time of this algorithm varies on networks with different size, which mainly depends on the number of source, destination, and relay nodes of the networks. The most time-consuming part is applying maximum weighted bipartite matching algorithm. Simulation of this algorithm works only 40 to 500 nodes.
- In this approach, each relay node serves at most one source node depending on capacity calculation. Relay nodes of this approach require better scheduling technique to handle significant number of source nodes. Although TDMA-based scheduling is used, which requires additional input filters and frequency conversion because in cooperative networks, relay nodes use both uplink and downlink transmission to receive and forward packets.
- This approach assumes that orthogonal channels are available into the network to mitigate interference, which is impractical for network point of view.

3.2. Energy-Efficient Relay Selection

Power control mechanism is a challenging issue in cooperative wireless networks. Relay node selection versus power optimization is an important objective function for some energy constraint networks such as ad hoc and sensor networks. In [16], the authors study the joint relay node assignment and power allocation problem to save the power consumption under the bandwidth constraint. The authors proposed a polynomial time joint relay and power allocation (JRPA) algorithm which considers the energy efficiency of the network. The objective of this approach is given by

$$\text{Min} \left\{ \sum_{i=1}^{N_s} P_{s_i} + \sum_{j=1}^{N_r} P_{r_j} \right\} \quad (10)$$

here P_s and P_r denote the assigned powers for source node s and relay node r under the fixed bandwidth requirements, respectively.

The main idea of JRPA can be explained in three parts:

- **Bipartite graph construction:** A weighted bipartite graph G is created based on the transmission pair set X and relay node set Y . The weights of edges is calculated based on the Equations (2) and (4), which actually estimate the channel gain information between source–destination and source–relay nodes.
- **Saturated matching procedure:** Apply K-mean algorithm to find out a maximum saturated matching.
- **Relay node assignment:** Finally, the relay node is assigned to the transmission pair T , $\mathcal{R}(T_i) = r_{M(i)}$ where $M(i) < N_r$, where $i = 1$ to N_t and N_t and N_r denote total number of transmission pair and relay nodes, respectively.

The strong aspect of this approach are:

- This approach shows that each node using fixed transmission power. The cooperative communication with appropriate relay selection can offer a larger capacity than that under direct transmission.
- Simulation part of this algorithm shows that it can save 34.2% energy compared to direct transmission and 18.9% to the ORA [13] schemes. Based on this result, it can be decided that cooperative communication with proper relay node selection can provide the required bandwidth with a smaller transmission power on each node.

However, the JPRA shows the following limitations in relay selection problem.

- Simulation part of this algorithm considers the impact of the number of the source–destination pairs on the total power consumptions under the uniform bandwidth and random bandwidth requirements. In both cases, the total power consumption is increasing as the increasing rate of number of transmission pair. The authors do not show any optimal and threshold value of the number of transmission pairs under the heavy load condition.
- The running of this approach depends on the number of transmission pair and relay node assigned on the networks. Complexity of this approach depends on the number of nodes in the networks. The most time consuming part is bipartite graph construction.

Similarly, in [15], the authors study relay selection and optimal power allocation in AF networks and propose a semi distributed algorithm. It uses centralized method of relay selection. The authors consider the system model as shown in Figure 5 [15].

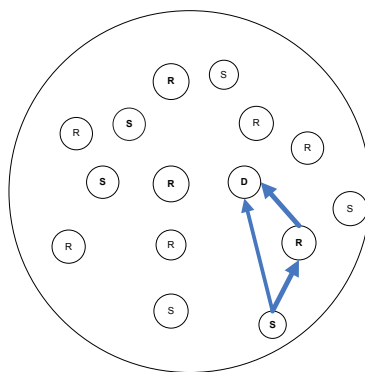


Figure 5. System model of the wireless network (from work in [15]).

The network consists of multiple source and dedicated relay and a single destination node. Here, each source node searches relay node form a set of feasible relay nodes and selects the one which maximizes the following expression.

$$i = \arg \max \left\{ \frac{\beta_{sj}\beta_{jd}SNR}{(\beta_{sj} + \beta_{jd})SNR + 1} \right\} \quad (11)$$

where SNR is the signal to noise ratio at the transmitting node, $\beta_{sj} = |\alpha_{sj}|^2$, and $\beta_{jd} = |\alpha_{jd}|^2$, where α_{sj} and α_{jd} are the channel coefficient from source to relay and relay to destination node respectively. After selecting the best relay node, the power allocation can be applied to further improve the capacity performance. The derivation of optimal power allocation is given by

$$\max_{P_s, P_i} f(P_s, P_i) \quad \text{subject to } P_s + P_i = P_{max} \text{ and } P_s, P_i > 0 \quad (12)$$

The semi-distributed algorithm is divided into two steps:

- **Feasible set generation:** In the first phase, the relay nodes using handshaking packets such as request to send (RTS) and clear to send (CTS) estimate the channel gains from the source and destination nodes. Then, all relay nodes hence decide on their feasibility and report their node indices to the destination.
- **Relay node allocation:** Run the destination-based relay selection method where the destination selects relay node from the feasible set and assigning it to one of the source nodes.

Some limitation of this approach are:

- High computational complexity due to apply power allocation with relay selection. The trade-off between the performance improvement by optimal power allocation and computational complexity need to be addressed .
- The feasible set of relay nodes depends on SNR value of the transmission pairs. The larger SNR values reduce the size of the feasible node set because when SNR becomes sufficiently large, the direct transmission becomes only choice.
- In this schema, the inter-user interference is omitted by assuming the availability of orthogonal channels in the network. OFDMA multiple access is used but how to combat this interference is not addressed here.

3.3. Relay Selection and Coverage Expansion

The coverage area extension in wireless network is an important issue of cooperative communication. The spatial diversity nature of cooperative communication improves the coverage area of wireless network without increasing infrastructure [23]. In Figure 6 illustrates the difference between the direct transmission and cooperative transmission schemes.

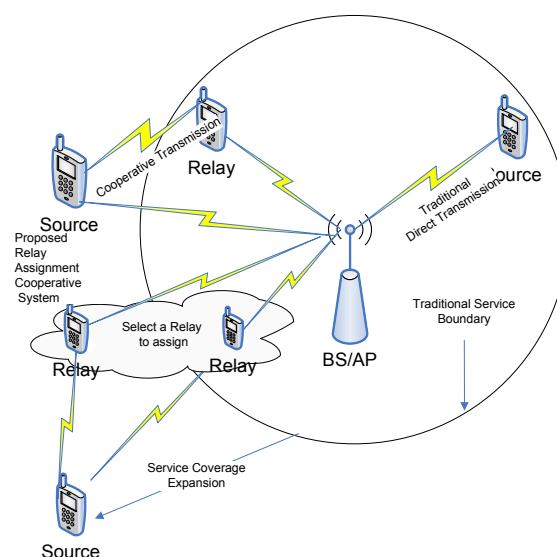


Figure 6. Coverage extension and relay selection (from work in [23]).

The authors derive the optimal relay location based on two case. The first case considers the destination uses packets from relay as well as source nodes after maximum ratio combining (MRC) for detection and second case is destination uses packets only from relay node(no-MRC). In the MRC case, the optimal relay location from the destination is given as

$$x^* = \frac{1}{1 + \frac{1}{2^{\frac{1}{\alpha-1}}}} \quad (13)$$

where α is the path loss exponent. In case $\alpha \geq 2$, then $x^* > 0.5$, which means the optimal relay position is closer to the source node. In the case of no-MRC at the receiver, the optimal relay position is shown to be at the middle point between the source and destination. In both case, authors derive minimum outage probability of source node to relay node and estimate the optimal relay location. The authors then proposed two distributed algorithms-nearest neighbour routing in which the relay nearest to the source can be selected as a helper. The second is infrastructure based relay assignment in which fixed relays are deployed in the network to help the users.

3.4. Interference Mitigation and Relay Selection

In multi hop wireless networks, interference associated with relay node degrade throughput and increase packet loss ratio. In [22], the authors consider ad hoc network environment with multiple active source–destination pairs and multiple relay nodes. Authors proposed a novel approach to mitigate interference by assigning appropriate relay nodes in the network. In [13,15], the authors assume that infinite number of orthogonal channels are available in networks which is impractical in real point of view. Typically, when multiple relay nodes use same channel, their transmission interfere with each other, might degrade the overall performance of the network. In [22], the authors consider interference produce by relay node. The system model they consider is given below.

In Figure 7, consider that the interference range is equal to transmission range and the dashed circle represents the transmission range of r_1 , r_2 , and r_3 and three source node choose r_1 , r_2 , and r_3 as their relay node. In this scenario, d_2 is in transmission range of r_1 , and r_2 and r_3 are in the same transmission range of each other. Therefore they cause interference to each other when they transmit message simultaneously. As a result flows 1–3 achieve at most half of the capacity. Considering this scenario, authors proposed a relay protocol that find out optimal assignment of relay node which mitigate the interference problem which was generated by inappropriate relay selection. The proposed schema maximize the average capacity in the wireless cooperative networks. The objective of this protocol is twofold.

- $i = \max avgC(s, d) = \max \frac{1}{N_s} \sum_{i=1}^{N_s} C(S_i)$
- Simultaneously, mitigate the interference for cooperative networks.

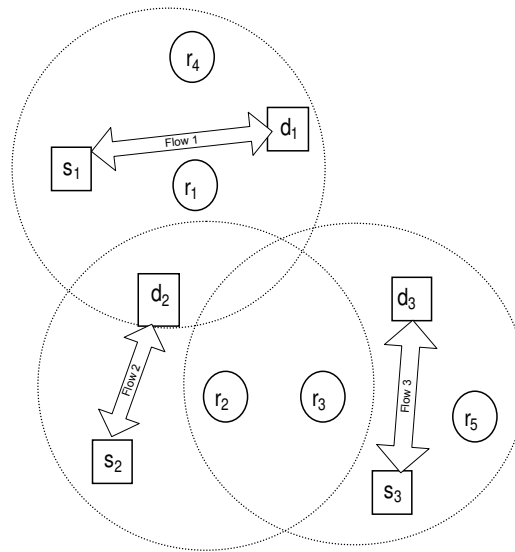


Figure 7. Ad hoc network environment where relay node may cause interference. From work in [22].

The protocol works on the following assumptions. (i) Interference are caused by only relay node, (ii) a table, called a CoopTable [31] of potential relay node, is maintained by each source node. CoopTable contains information about the channel conditions, interfered, and un-interfered status of relay node. Each information are updated periodically, and (iii) each node sends and receives the RTS. CTS and ACK signal without error. The ORAi algorithms works based on the Cooptable information. The processing steps involved in this algorithms are as follows.

- **Preprocessing step:** In this step, each node calculates channel capacity $C_{DF}(s_i, R(s_i), d_i)$ and $C_{DT}(s, d)$ with the information in Cooptable. Then, s_i selects the relay node which can maximize its capacity without considering the interference information.
- **Collision detection, negotiation, and final assignment:** Three control packets *request-reply* and *report* are used here. If $R(s_i)$ detects collisions, a request packet sends to the sender s_i . After receiving request packet, the sender s_i search a replacer in the current $R(s_i)$ in Cooptable. The replacer is selected when the replacer status is un-interfered, capacity must be higher than direct transmission and provide the maximum capacity gain among others nodes. If a replacer can be found, source sends the information of the replacer to $R(s_i)$ by *reply* packets. Next, $R(s_i)$ negotiates with interfered node and sends *report* packet to source about the replacer information.

Some limitations of this approach are as follows.

- This schema depends on the construction of Cooptable. Each source node maintains this table which need periodically update process when network condition varying.
- This protocol works on the assumption that only relay node can create impact the transmission on other nodes. However, in the real-time scenario, interference will occurred by any nodes.
- This protocol works like reactive fashion. First, each source node selects a relay node; if this relay causes any collision to others node, then negotiation and replacement procedure will happen. The overhead associate with this procedure generates new complexity and has side effect when a replacer concurrently try to replace others relay node.
- Lower spectrum efficiency and high computational complexity are major problem when multiple relay nodes provide service to each source.

3.5. Relay Selection Based on Local Information (Interference Factor, Mobility, and Transmission History)

Unlike the previous protocol, this relay selection process does not depend on channel state information, avoid periodic updates, or consequent broadcast information. In [32] authors introduce

a relay selection schemes named RelaySpot which considers interference, mobility and historical information related to relay node. Relay Spot algorithm comprises three parts: (i) Opportunistic relay selection, (ii) Cooperative relay scheduling, and (iii) Chain relaying mechanism. In opportunistic relay selection schema, each relay node computes the probability of selection factor and contention window size CW . The probability of selection factor S depends on interference, history, and mobility factors. First, *Interference factor* (I) is estimated by load and node degree. Node degree gives information about successful relay transmission. Interference factor is measured by

$$I = \sum_{j=1}^{N_d} (T_{dj} + T_{pj}) + \sum_{k=1}^{N_i} T_{ik}, \quad (14)$$

where N be the number of potential relay, T_d and T_i are the propagation time of direct and indirect transmission, respectively. Relay node can be selected based on low interference factor which ensures selected relay has few neighbors, short transmission, and few direct transmission. Second, *history factor* (H) is initialized in a time unit. The history factor is defined as the ratio between the duration of successful transmissions and the maximum duration of any successful transmission. Stability of the potential relay refers to as *mobility factor* (M). After deriving these three factors, the probability of selecting a node as relay is calculated for a given destination as

$$S = \frac{H * M}{1 + I}, S \in [0, 1] \quad (15)$$

Figure 8 shows a scenario, where node R and X both seem to be potential relay nodes, X shows low interference label closer to source, and R has a short transmission from its neighbor and long transmission from S . Authors assume that R shows a good history of successful transmission and moves frequently around the destination. According to Equation (15) the probability of selection factor of node R will be higher than node X . Each relay node uses this estimated selection factor S to compute the sizes of its contention window $CW = CW_{min} + (1 - S)(CW_{max} - CW_{min})$. The contention window plays an important role in scheduling among qualified relay nodes. Finally, the relay chain process happens when relay node or source node changes their position due to mobility as well as unstable wireless condition. Chain relaying process includes the possibility of using recursive relay selection and retransmission in case of poor performance. The strong aspects of this approach are as follows.

- Authors develop an interference-aware relay selection protocol and also considered the mobility factor of the node.
- This protocol minimizes signaling exchange, removes estimation of channel conditions and does not need any additional control signal.
- RelaySpot minimizes the outage and improve the overall throughput by applying cooperative scheduling techniques.
- Simulation result shows that selecting a relay node with low interference and lower number of concurrent neighbor flows lead to higher transmission opportunities.
- Interference-aware approach of relay selection also ensures low resource blockage.

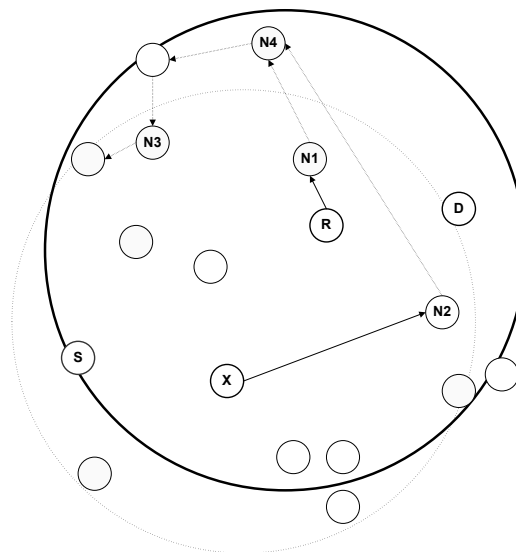


Figure 8. Opportunistic relay selection scenario (from work in [32]).

4. Conclusions and Future Work

The relay selection is a promising approach of maximizing the diversity gain achieved in cooperative networks. In other words, transmission performance is improved in wireless multi-user scenario allowing each user assists each other and acts as a virtual MIMO system by sharing their antennas in distributed way. In the past few years, the challenging issues of relay assignment problem have been researched and analyzed extensively. However, there are still more research issues to be investigated such as follows.

- How scheduling and synchronization process work when multiple relay nodes are selected to assist users.
- Investigation of the design issues of reservation process and resource allocation and relay selection in MAC layer.
- In multi-hop networks, how medium access control protocol supports multiple relay node.
- Recent researchers address the impact of interference that are produced by relay nodes. However, it is still a challenging task to investigate how the interference produced by the relays impact the relay selection process and network performance.
- For larger wireless sensor networks, the estimation of multi-hop route along with relay selection remains an interesting and challenging open problem.

Different relay selection schemes have different focus, criteria, objective, mechanisms, and performance issues. In this article, an overview of some relay selection schemes, their challenging issues, performance criteria, and mechanisms are discussed. Figure 3 highlights the main design issues of any relay selection scheme. Table 1 compares some relay selection algorithms in terms of different features. This paper also analyzes in detail to demonstrate the effect of channel capacity, power allocation, coverage expansion and interference mitigation in proper relay selection schemes.

Table 1. Comparison of various relay assignment schemes.

| Algorithm | Objective | Number of Transmission Pairs | Number of Relay Nodes | Selection Criteria and Mechanism | Selection Parameters | Strong Points |
|--|--|--|---|---|---|--|
| Optimal relay assignment algorithm ORA [13,33] | Find an optimal relay node assignment for all source and destination pairs such that minimum capacity among all pairs is maximum | Multiple source and multiple destination pairs | Single relay assignment schema. Multiple relay node but one relay is assigned to one source only. | Cooperative and distributed approach | Channel state information and signal to noise ratio | Provide an optimal solution, polynomial time algorithm |
| Capacity maximization and optimal relay assignment OPRA [14] | Maximize the total capacity of the networks | Multiple Source-destination pairs | Multiple relay nodes but one relay node can be shared by multiple source nodes | Cooperative and distributed approach | Depends on channel state information and signal to noise ratio | Polynomial time algorithm, TDMA Scheduling is used. |
| Output threshold-based relay selection [7] | Increase throughput and minimize outage | Multiple transmission pairs | Multiple relay selection schema. | Cooperative and Destination assign relay node. | Depends on CSI and SNR value | Less channel estimation requirements and lower power consumption. |
| Interference-aware relay assignment ORAi [22] | Interference mitigation and maximize the average capacity of the networks | Multiple source-destination pairs | Multiple relay assignment schema. One source can use multiple relay nodes. | Cooperative, table based schema | Estimate the impact of interference produced by relay nodes, works on channel state information(CSI) | Estimate conflict flow capacity and adjust flow through negotiation process. Interference mitigation process minimize collision of the network. |
| Joint relay and power allocation JRPA [16] | Minimize the total power consumption of the networks | Multiple source-destination pairs | Single relay assignment schema. One relay assign to one source. | Cooperative and centralized approach | Analyze minimum power consumption and estimate optimal power allocation under different bandwidths requirements | Polynomial time algorithm, consider different bandwidth requirements |
| Semi-distributed Algorithm [15] | Power allocation for AF wireless relay network | Multiple source-destination pairs | Single relay selection schema | Distributed approach | Comparing channel gain with predefined threshold and construct feasible relay sets. | Derive threshold-based necessary and sufficient condition which is used in relaying algorithm .Algorithm shows lower computational complexity and system overhead. |
| Table based relay selection [31] | Ensure diversity and enhance data rate | Single source destination pairs | Single relay assignment | Source-based, centralized and cooperative mechanism | Estimate real-time CSI value. | Simple mechanism and easy to compute. |
| Coverage expansion and infrastructure based relay selection [23] | Find optimal relay location to minimize outage probability. | Multiple source but single destination. | Single relay assignment schema. One relay serve more than one source. | Distributed approach | Estimate distance and outage probability. | Appropriate relay node significantly increase in coverage area, minimize outage. |
| Priority list based distributed partner selection [34] | Diversity improvement | Multiple source destination pairs | Multiple relay assignment | Distributed approach | Estimate signal to noise ratio, outage probability and create a priority list depends on this two value | Fixed priority list based selection schema achieve full diversity gain. |
| Priority list based centralized partner selection [34] | Minimize the average node outage across the network. | Multiple source destination pairs | Multiple relay assignment | Centralized approach | Estimate outage probability-based on channel information. | Simple and relay selection based on physical location. |
| Mobility and transmission history based relay selection RelaySpot [32] | Minimize signaling exchange ratio and improve reliability. | Multiple transmission pairs | Single relay assignment schema | Opportunistic relay selection. | Estimate interference factor, mobility and transmission history. | Increase throughput and reliability. Reduce control overhead by omitting the estimation of channel condition. |

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References

1. Ferdouse, L.; Anpalagan, A. Relay selection based on bayesian decision theory in cooperative wireless networks. *Can. J. Electr. Comput. Eng.* **2015**, *38*, 116–124. [\[CrossRef\]](#)
2. Shah, V.K.; Gharage, A.P. A review on relay selection techniques in cooperative communication. *Int. J. Eng. Innov. Technol.* **2012**, *2*, 65–69.
3. Laneman, D.J.N.; Wornell, G. Cooperative diversity in wireless networks: Efficient protocol and outage behaviour. *IEEE Trans. Inf. Theory* **2004**, *50*, 3062–3080. [\[CrossRef\]](#)
4. Mahmood, A. Cooperative diversity in wireless networks. *J. Eng. Sci. Technol. Rev.* **2010**, *3*, 184–187. [\[CrossRef\]](#)
5. Tan, H.K.; Wan, Z.; Andrian, J. CODE: Cooperative medium access for multimate wireless Ad hoc network. *IEEE SECON* **2007**, 1–10. [\[CrossRef\]](#)
6. Senanayake, R.; Atapattu, S.; Evans, J.; Smith, P. Decentralized relay selection in multi-user multihop decode-and-forward relay networks. *IEEE Trans. Wirel. Commun.* **2018**, *17*, 3313–3326. [\[CrossRef\]](#)
7. Amarasuriya, M.G.; Tellambura, C. Output-threshold multiple relay selection scheme for cooperative wireless networks. *IEEE Trans. Veh. Technol.* **2010**, *59*, 3091–3097. [\[CrossRef\]](#)
8. Ju, J.; Duan, W.; Sun, Q.; Gao, S.; Zhang, G. Performance analysis for cooperative noma with opportunistic relay selection. *IEEE Access* **2019**, *7*, 131488–131500. [\[CrossRef\]](#)
9. Zhu, Y.; Li, Z.; Sui, D.; Li, D.; Kong, J.; Hu, F. Group-based relay selection in simultaneous wireless information and power transfer network. *IEEE Access* **2018**, *6*, 49019–49028. [\[CrossRef\]](#)
10. Xie, K.; Wang, X.; Liu, X.; Wen, J.; Cao, J. Interference-aware cooperative communication in multi-radio multi-channel wireless networks. *IEEE Trans. Comput.* **2016**, *65*, 1528–1542. [\[CrossRef\]](#)
11. Shan, H.; Wang, P.; Zhang, W.; Wang, Z. Cross-layer cooperative triple busy tone multiple access for wireless networks. In Proceedings of the IEEE GLOBECOM 2008—2008 IEEE Global Telecommunications Conference, New Orleans, LO, USA, 30 November–4 December 2008; pp. 1–5.
12. Li, E.; Wang, X.; Dong, Y.; Li, Y. Research on the nth-best relay selection with outdated feedback in selection cooperation systems. *Wirel. Pers. Commun.* **2016**, *89*, 45–59. [\[CrossRef\]](#)
13. Sharma, Y.H.S.; Shi, Y.; Kompella, S. An optimal algorithm for relay node assignment in cooperative add hoc networks. *IEEE Trans. Netw.* **2011**, *19*, 877–892. [\[CrossRef\]](#)
14. Yang, D.; Fang, X.; Xue, G. OPRA: Optimal relay assignment for capacity maximization in cooperative networks. In Proceedings of the IEEE International Conference on Communications (ICC), Kyoto, Japan, 5–9 June 2011; pp. 1–6.
15. Cai, J.J.; Shen, S.; Alfa, A. Semi-distributed user relaying algorithm for amplify and forward wireless relay networks. *IEEE Trans. Wirel. Commun.* **2008**, *7*, 1348–1357.
16. Xu, L.H.; Liu, G. Joint relay assignment and power allocation for cooperative for cooperative communication. *Wirel. Netw.* **2010**, *16*, 2209–2219. [\[CrossRef\]](#)
17. Saghezchi, F.; Radwan, A.; Rodriguez, J. Energy-aware relay selection in cooperative wireless networks: An assignment game approach. *Ad Hoc Netw.* **2017**, *56*, 96–108. [\[CrossRef\]](#)
18. Arroyo-Valles, R.; Simonetto, A.; Leus, G. Consistent sensor, relay, and link selection in wireless sensor networks. *Signal Process.* **2017**, *140*, 32–44. [\[CrossRef\]](#)
19. Bletsas, D.A.; Lippman, A. A simple cooperative diversity method based on network path selection. *IEEE J. Sel. Areas Commun.* **2006**, *24*, 659–670. [\[CrossRef\]](#)
20. Alam, M.; Kaddoum, G.; Agba, B. A novel relay selection strategy of cooperative network impaired by bursty impulsive noise. *IEEE Trans. Veh. Technol.* **2019**, *68*, 6622–6635. [\[CrossRef\]](#)
21. Hassan, J.; Mustafa, S. An efficient partner selection method to overcome the interference effect in wireless networks. *IEEE Access* **2019**, *7*, 33677–33685. [\[CrossRef\]](#)
22. Zhang, F.P.; Xu, Z.; Tu, L. A relay assignment algorithm with interference mitigation for cooperative communication. *IEEE J. Sel. Areas Commun.* **2007**, *25*, 328–339.
23. Sadek, Z.A.K.; Lui, K.J.R. Distributed relay-assignment protocols for coverage expansion in cooperative wireless networks. *IEEE Trans. Mob. Comput.* **2010**, *9*, 505–515. [\[CrossRef\]](#)

24. Lee, I.-H.; Jung, H. Energy-efficient path selection using snr correlation for wireless multi-hop cooperative communications. *Energies* **2018**, *11*, 3004. [\[CrossRef\]](#)
25. Onat, F.A.; Fan, Y.; Yanikomeroglu, H.; Poor, H. Threshold-based relay selection for detect and forward relaying in cooperative wireless networks. *EURASIP J. Wirel. Commun. Netw.* **2010**, 1–9. [\[CrossRef\]](#)
26. Afzal, M.; Nam, S.Y.; Kim, B.-S.; Kim, S.W. Snr-based relay selection in cooperative wireless ad hoc networks. *Int. J. Ad Hoc Ubiquitous Comput.* **2018**, *28*, 45–54. [\[CrossRef\]](#)
27. Ng, T.C.Y.; Yu, W. Joint optimization of relay strategies and resource allocation in cooperative cellular networks. *IEEE J. Sel. Areas Commun.* **2007**, *25*, 328–339. [\[CrossRef\]](#)
28. Su, Y.; Lu, X.; Zhao, Y.; Huang, L.; Du, X. Cooperative communications with relay selection based on deep reinforcement learning in wireless sensor networks. *IEEE Sensors J.* **2019**, *19*, 9561–9569. [\[CrossRef\]](#)
29. Nguyen, T.T.; Lee, J.H.; Nguyen, M.T.; Kim, Y.H. Machine learning-based relay selection for secure transmission in multi-hop df relay networks. *Electronics* **2019**, *8*, 949. [\[CrossRef\]](#)
30. Xu, S.; Wang, F. Analysis and comparison of relay node selection algorithm of cooperative communication. *Inf. Technol. J.* **2013**, *12*, 434–438.
31. Pei, N.T.L.; Zhifeng, T.; Panwar, S. CoopMAC: A cooperative MAC for wireless LANs. *IEEE J. Sel. Areas Commun.* **2007**, *25*, 340–354.
32. Jamal, P.T.; Zuquete, A. Wireless cooperative relaying based on opportunistic relay selection. *Int. J. Adv. Netw. Serv.* **2012**, *5*, 116–128.
33. Shi, Y.H.Y.; Sharma, S.; Kompella, S. Optimal relay assignment in cooperative communications. In Proceedings of the 9th ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc08), 26–30 May 2008; pp. 3–12. [\[CrossRef\]](#)
34. Nosratinia, A.; Hunter, T.E. Grouping and partner selection in cooperative wireless networks. *IEEE J. Sel. Areas Commun.* **2007**, *25*, 369–378. [\[CrossRef\]](#)



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