

A New User-Centric Grouping Scheme for Relay Terminals in the Millimeter-Wave Band

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Abstract— This paper proposes a new user-centric grouping scheme of relay terminal for device-to-device (D2D) link in the millimeter-wave (mmWave) band. Recently, sixth generation (6G) and future wireless communication systems utilize high-frequency bands such as mmWave. However, obstacles easily block these mmWave signals. Signal blockage causes frequent path disconnections. D2D relaying provides an effective approach to blockage-affected disconnections. Conventional D2D relaying relies on a single relay terminal. A blockage on the single relay path significantly degrades communication quality and causes complete disconnections. Therefore, we propose a user-centric relay terminal grouping scheme. The proposed scheme dynamically groups multiple candidate relay terminals, which communicate with a remote radio unit (RRU) as user equipment (UE). The proposed scheme flexibly utilizes multiple paths. Consequently, the proposed scheme achieves about 25% improvement of the average transmission capacity over the conventional scheme in the mmWave blockage environment employing the distributed MIMO systems.

Index Terms—millimeter-wave, blockage, distributed MIMO, relay grouping, cooperative relay

I. INTRODUCTION

Current commercial wireless communication services mainly utilize the microwave band from 3 GHz to 30 GHz [1]. Sixth generation (6G) and future wireless communication systems require higher transmission capacity. Therefore, to realize high-capacity transmission, future systems utilize high-frequency bands such as millimeter-wave (mmWave) bands. However, these high-frequency bands are greatly affected by propagation loss because of blockage and building environment [2], [3]. The large propagation loss reduces the received power compared to the microwave band. Characteristics of straight-line propagation in mmWave also decreases diffraction waves compared to the microwave band [4]. Therefore, blockages cause attenuation of several tens of dB [5], [6]. Moreover, moving obstacles like pedestrians and vehicles cause blockages. Urban and indoor environments involve frequent movements of users and obstacles. In these environments, obstacles suddenly block the line-of-sight (LOS) path between the remote radio unit (RRU) and the user equipment (UE). LOS blockage causes frequent disconnections. The resulting disconnection degrades communication quality and coverage. The literature [7], [8] describes device-to-device (D2D) communication and relay technologies to solve blockage-induced disconnections.

On the other hand, the conventional cellular configuration performs direct communication between the RRU and the UE. D2D communication utilizes nearby UEs as relay systems. However, most conventional relay schemes employ single-hop relaying or static routing [9-11]. These schemes rely on a single relay terminal. A single-path system cannot realize an alternative path immediately. Link quality decreases when obstacles block the relay terminal. Movement of terminals and obstacles also degrades link quality. These events cause disconnections. The blockage environment in mmWave bands is severe problems for realizing relay schemes to establish stable high-quality transmission systems.

To solve this problem, we propose a new user-centric grouping scheme for relay terminals. The proposed approach does not rely on a single transmission path. The proposed scheme dynamically groups multiple UEs. In addition, we assume that these UEs are also equipped with relaying functions. Thus, the proposed user-centric grouping scheme realizes cooperative relaying.

II. CONVENTIONAL SCHEME

Section II describes three conventional relay schemes and clarifies their limitations in mmWave blockage environments.

A. Cooperative Communication and Virtual Antenna Arrays

Conventional cooperative systems use D2D communication. This D2D communication forms a virtual antenna array [9]. These terminals act as relay nodes. Moreover, relay nodes have independent paths. These paths provide spatial diversity, which maintains connections in microwave bands. Microwave signals effectively diffract in non-line-of-sight (NLOS) conditions. However, mmWave signals lack diffraction capability. Moving obstacles block mmWave paths easily. Moving blockage causes a sudden drop in received power. Therefore, virtual antenna arrays fail during sudden blockages.

B. Network Controlled Repeater (NCR)

The 3GPP release 18 standardizes the network-controlled repeater (NCR) [10]. The base station controls the NCR. The NCR performs beamforming. NCR beamforming eliminates coverage holes. However, the NCR has two major limitations. First, operators install the NCR on fixed infrastructure like utility poles. Fixed NCR installation increases costs and reduces deployment flexibility. Second, the NCR performs single-hop relaying. The NCR amplifies and forwards specific paths. Moving obstacles often block the RRU-to-NCR link or the NCR-to-terminal link. The NCR lacks alternative routing

paths. Therefore, the fixed single-point relay cannot guarantee sufficient reliability.

C. NR Sidelink Relay

The 5G new radio (NR) defines sidelink communication for vehicle-to-everything (V2X) [11]. The NR sidelink enables direct communication among terminals. Out-of-coverage terminals connect to the network via relay terminals. This system enables autonomous relaying. However, the NR sidelink primarily targets proximity information exchange. The NR sidelink does not dynamically optimize routing paths to avoid blockages.

Therefore, we require an approach to stable mmWave communication. The system must not rely on specific fixed stations or single relay terminals. The system must dynamically group multiple candidate terminals. In this situation, we utilize the redundancy of multi-terminal grouping.

III. PROPOSED SCHEME

This section proposed a new user-centric grouping scheme for relay terminals in the millimeter-wave band. The proposed scheme assumes that all UEs have relay capabilities. UEs normally communicate with RRU directly. When UE detects the received carrier-to-noise ratio (C/N) is falling below the required threshold, the UE initiates the transmission of a support request signal. Sending this support request signal triggers the start of a search for nearby relay candidate terminals.

A. Grouping Scheme

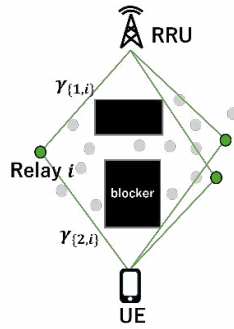


Fig. 1. Proposed grouping scheme.

The proposed scheme evaluates both links of each relay candidate terminal. Figure 1 shows the proposed grouping scheme. Let $\gamma_{1,i}$ be the received C/N at relay candidate i from the RRU (Hop 1). Let $\gamma_{2,i}$ be the received C/N at the target UE from relay candidate i (Hop 2). The algorithm selects the lower value between the two links as a total score P_i :

$$P_i = \min(\gamma_{(1,i)}, \gamma_{(2,i)}) \quad (1)$$

P_i represents the minimum communication quality guaranteed across the entire path. The proposed scheme calculates P_i for all candidate terminals. Then, it sorts the terminals from higher order of P_i . The scheme selects the top k terminals to form a proposed relay group.

As shown in Figure 1, the scoring policy excludes inappropriate terminals from the relay group. For instance, a terminal might have a high link quality on Hop 1, but a blocked link on Hop 2. Another terminal might have a blocked

link on Hop 1, but a high link quality on Hop 2. Both terminals obtain low P_i scores. Therefore, the algorithm eliminates these unbalanced terminals. As a result, the relay group consists of only balanced terminals. Every selected terminal maintains adequate quality across over the entire link.

B. Multi-RRU Extension

We extend the proposed scheme to a distributed MIMO environment with multiple RRUs. In this environment, the proposed scheme causes a relay-terminal concentrated problem. Figure 2 illustrates this problem. High-quality relay terminals sometimes concentrate near a specific RRU. In this case, the system selects multiple terminals routing through this specific RRU and does not utilize other available RRUs. To avoid this concentration and create independent links, we extend the proposed scheme to assign each terminal to an appropriate RRU before group selection.

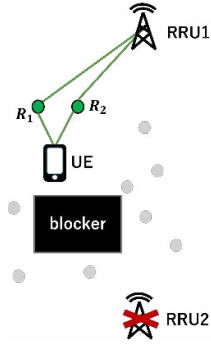


Fig. 2. Problem of relay-terminal concentration in a multiple-RRU environment.

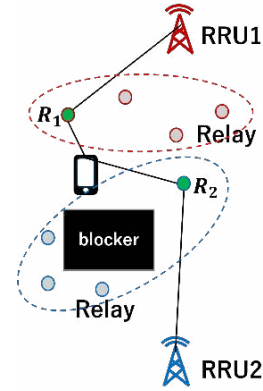


Fig. 3. Extended grouping scheme.

The proposed extended procedure consists of four steps, as shown in Figure 3:

1) Each candidate terminal measures the received C/N from all available RRUs, such as RRU1 and RRU2.

2) Each candidate terminal associates with the RRU providing the highest C/N . We classify terminals into RRU1-assigned and RRU2-assigned groups:

$$\gamma_{(1,i)}(RRU1) > \gamma_{(1,i)}(RRU2) \Rightarrow RRU1 \text{ Assigned} \quad (2)$$

$$\gamma_{(1,i)}(RRU1) \leq \gamma_{(1,i)}(RRU2) \Rightarrow RRU2 \text{ Assigned} \quad (3)$$

3) Each terminal calculates P_i for each assigned group. The extended proposed scheme uses the received C/N from the assigned RRU.

4) The extended scheme selects one terminal with the maximum score P_i from each RRU group.

The extended algorithm expands the selection of candidate links to include multiple RRUs. Expanded link selection avoids the relay-terminal concentration problem to a specific RRU.

IV. CONNECTION CONTROL

This section describes the operation-state transition of the proposed scheme.

A. Basic Connection Control Flow

Figure 4 shows the basic connection control flow model of the proposed scheme. First, the UE communicates with the RRU directly. Direct RRU communication represents the Direct state. Obstacles block the direct path. Direct-path blockage drops the received C/N below a required threshold. Second, the scheme transitions to the Searching state. It searches for candidate relay terminals. The scheme detects available k terminals, where k is the number of relay terminals. The system completes the grouping process. Third, the scheme transitions to the Relaying state. The UE starts communication via the relay terminals. On the other hand, the scheme might find fewer than k qualified terminals during a searching state. When fewer than k terminals are available, the UE returns to the Direct state. Last, the UE moves out of the blockage area. The direct communication quality recovers. Then, the UE releases the relay connection. The UE returns to the Direct state.

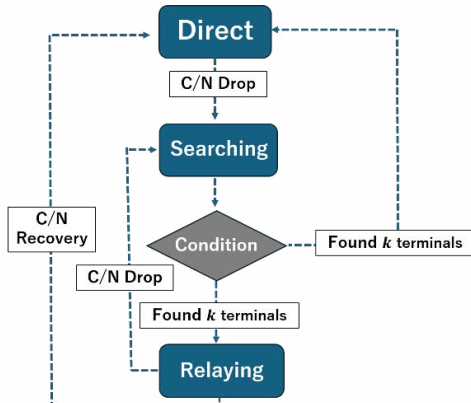


Fig. 4. Basic connection control flow model of UE.

B. Variable- k Algorithm

The basic connection control flow in the previous description uses a fixed relay number k . This fixed- k algorithm requires exactly k qualified terminals. This case aborts the relay process when available terminals are fewer than k . The relay-process termination causes link disconnections.

Therefore, we introduce the variable- k algorithm to prevent this sudden disconnection. This algorithm decreases the number of relay terminals dynamically. The algorithm consists of the following steps.

- 1) The searching state attempts group formation with k terminals.
- 2) The searching state calculates P_i .

3) The searching state starts relaying process, when the received C/N satisfies the required threshold.

4) The received C/N falls below the threshold. Then, the algorithm reduces the target relay number k by one. Then, the algorithm removes the terminal with the lowest score.

5) This algorithm recalculates P_i . The algorithm returns to Step 4 and repeats the process. The loop stops when the quality meets the threshold or the relay terminal count reaches one. Thus, the variable- k algorithm maximizes capacity and enhance keeping link connection.

V. PERFORMANCE EVALUATION

This section describes performance evaluation of the proposed scheme with the computer simulation. Table I summarizes the simulation parameters. This evaluation employs two simulation environments. The first environment is a single-RRU environment shown in Figure 5. The second environment is a multiple-RRU environment shown in Figure 6.

TABLE I Simulation parameters.

Parameter	Value
Carrier frequency	100 GHz
Bandwidth	400 MHz
RRU transmit power	20 dBm
RRU transmit antenna gain	10 dBi
UE transmit power	7 dBm
UE transmit antenna gain	10 dBi
UE receive antenna gain	20 dBi
Simulation area	40 m $\times$ 40 m

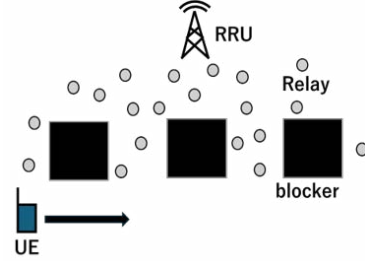


Fig. 5. Single-RRU simulation environment.

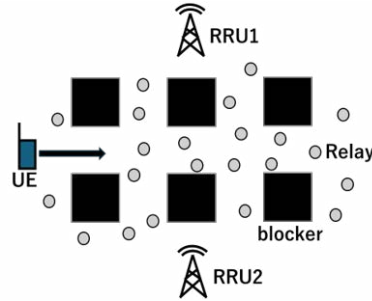


Fig. 6. Multiple-RRU simulation environment.

A. Simulation Setup

First, as shown in Figure 5, the single-RRU environment has three obstacles. The system distributes 100 candidate relay terminals randomly in the RRU side area. Figure 5 assumes a cell-edge environment. Therefore, the distribution of candidate terminals biases toward the RRU side from the target UE. The target UE moves straight at a constant speed of 4.0 km/h along the arrow in the figure. Selected relay

terminals perform ideally phase-aligned cooperative transmission. We model the selected relay terminals as a virtual transmit antenna array [12], [13]. Moreover, we evaluate the capacity based on the Shannon capacity formula [13].

Second, as shown in Figure 6, the multiple-RRU environment assumes a basic distributed MIMO systems with two RRUs. We place obstacles and candidate relay terminals between the opposed RRU1 and RRU2. The target UE moves straight at a constant speed of 4.0 km/h along the arrow in the figure. We evaluate the transmission capacity of the MIMO transmission based on the literature [14].

B. Numerical Results in Single-RRU Environment

This section evaluates the average transmission capacity in the single-RRU environment. Figure 7 and Figure 8, 9 illustrate the capacity under ideal and constrained conditions, respectively. The evaluation varies the relay number k from 1 to 10.

1) Evaluation Under Ideal Conditions

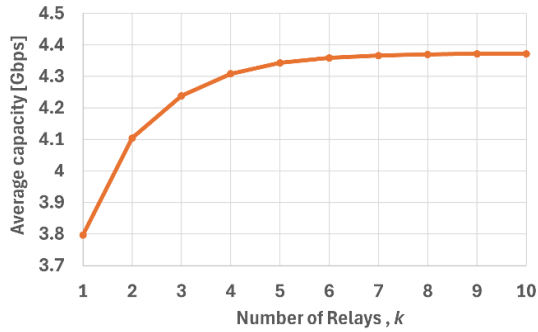


Fig. 7. Average transmission capacity against the number of relay terminals under ideal conditions.

The ideal scenario ignores the search delays and grouping process failures shown in Section IV. In this scenario, the capacity improves monotonically as k increases. The proposed scheme achieves a maximum capacity increase of approximately 15% compared to the $k=1$ case, as a single relay conventional scheme.

2) Evaluation Under Constrained Conditions

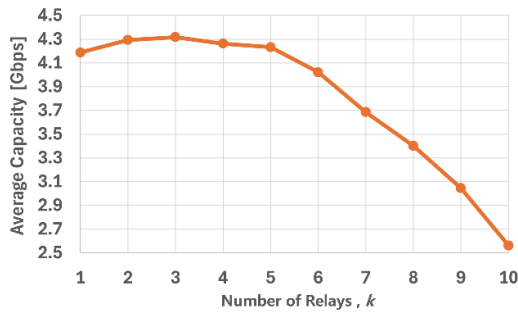


Fig. 8. Average transmission capacity of the fixed- k scheme under constrained conditions.

The constrained scenario employs the practical connection control flow described in Section IV. Figure 8 shows the capacity of the basic control flow with fixed- k algorithm. The capacity peaks at approximately 4.34 Gbps at $k=3$ and drops significantly to about 2.97 Gbps at $k=10$. A large k requirement makes it difficult to select qualified relay terminals because of increasing grouping selection failures.

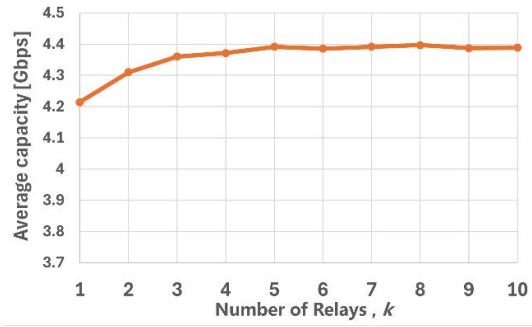


Fig. 9. Average transmission capacity of the variable- k strategy under constrained conditions.

Figure 9 shows the capacity of the variable- k algorithm. The capacity reaches about 4.39 Gbps around $k=5$ and remains stable at this high level up to $k=10$. The variable- k algorithm autonomously selects the subset of terminals by excluding poor-quality nodes with decreasing k . These results show that the variable- k algorithm reduces opportunities for direct communication drastically.

C. Numerical Results in Multiple-RRU Environment

This subsection evaluates basic performance in the multiple-RRU environment. This simulation compares conventional ($k=1$), proposed and proposed (extended) schemes. The proposed scheme corresponds to the grouping scheme described in Section III-A. The proposed (extended) scheme corresponds to the extended grouping scheme described in Section III-B. Moreover, for basic performance comparison, in all schemes, we also assume that the UE can receive the two data streams. We also use the fixed- k algorithm because of $k=2$ environment.

1) Transmission Capacity over Predefined Routes

First, the evaluation examines transmission capacity along the UE routes. We assume the relay-terminal constrained conditions described in Section IV. The target UE receives up to two data streams. The proposed schemes select a total of two relay terminals ($k=2$).

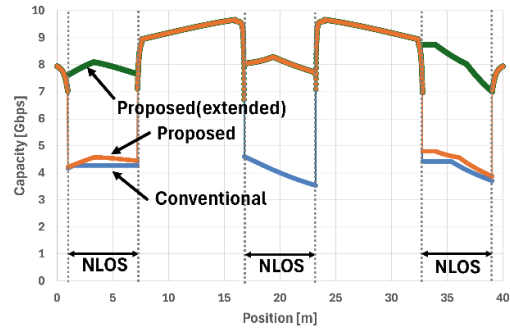


Fig. 10. Transmission capacity along the UE route under blockage environments.

Figure 10 shows the transmission capacity during the blockage area transit. The conventional scheme maintains approximately 4 Gbps in the NLOS region. The conventional scheme relies on a single path. Therefore, the conventional scheme lacks the spatial multiplexing gain.

The proposed scheme achieves a higher capacity than the conventional scheme. However, the capacity of the proposed scheme drops at specific locations, for example from about 2

m to 7 m. The proposed scheme sometimes selects high-quality relay terminals connected to the same RRU. This selection degrades the spatial multiplexing performance.

In contrast, the proposed (extended) scheme maintains a stable capacity that ranges from approximately 7.0 Gbps to 9.5 Gbps in the blockage area. The proposed (extended) scheme appropriately realizes terminal selection between RRU1 and RRU2 employing multiple independent paths. Consequently, the proposed (extended) scheme achieves the highest transmission capacity.

2) CDF Analysis of Transmission Capacity

Second, we evaluate the transmission capacity in 1000 independent trials. Figure 11 shows the cumulative distribution function (CDF) of the transmission capacity samples obtained at all movement steps over all trials. In the conventional scheme, the capacity ranged from approximately 4.0 Gbps to 8.0 Gbps due to blockage. The conventional scheme uses only one relay terminal during blockages area. The capacity of about 8.0 Gbps represents unblocked conditions and reflects the performance of direct LOS communication.

The proposed scheme uses two relay terminals and achieves high overall performance. However, at a CDF of approximately 7%, the proposed scheme achieves a capacity ranging from approximately 3.8 Gbps to 5.5 Gbps. This is because the selected relay terminals tend to connect to a specific RRU. A communication path on one BS stream degrades the spatial multiplexing gain. Consequently, the total transmission capacity decreases.

The proposed (extended) scheme eliminates low-capacity cases below 6.0 Gbps. The proposed (extended) scheme achieves the highest capacity of approximately 7.8 Gbps at a CDF = 50%. We found that the proposed (extended) appropriately selects two RRUs to increase the spatial multiplexing gain.

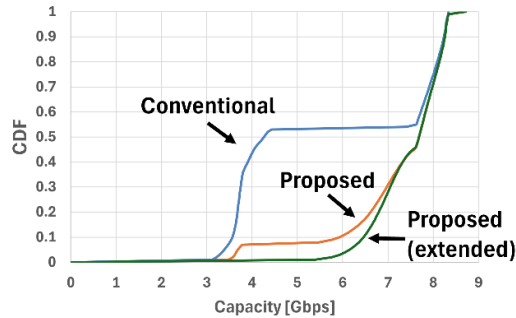


Fig. 11. CDF performance of the transmission capacity in multiple RRU environments.

3) Impact of Candidate Terminal Density

Last, Figure 12 shows average transmission capacity against the number of candidate relay terminals. We found that limited transmission capacity for both proposed and proposed (extended) schemes in low-density regions compared to the conventional scheme. Both schemes adopt selection criteria considering both RRU-Relay and Relay-UE link qualities. Therefore, low-density environments lack sufficient relay terminals satisfying these criteria. On the other hand, the transmission capacity of both schemes improves as the number of candidate relay terminals increases. The proposed (extended) scheme shows higher performance than the proposed scheme, especially in high

density regions. This is because the proposed (extended) appropriately uses the two relays linked to different RRUs. The proposed (extended) scheme achieves a maximum transmission capacity of approximately 8.5 Gbps under the condition of 150 candidate terminals. The proposed (extended) also indicates a maximum transmission capacity of approximately 25% improvement over the conventional scheme in the multiple RRU environment.

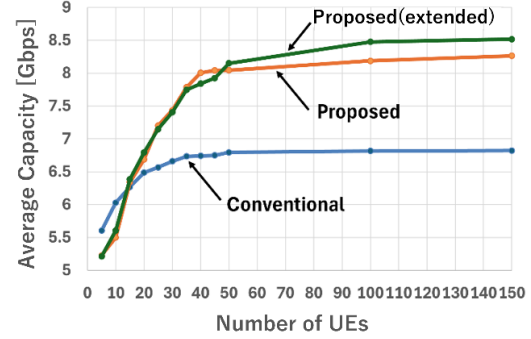


Fig. 12. Average transmission capacity against the number of candidate relay terminals.

VI. CONCLUSIONS

This paper has proposed a new relay terminal grouping scheme for mmWave band. First, in single-RRU environment, the proposed scheme achieved a maximum 15% capacity increase compared to the single relay conventional scheme under ideal conditions. However, the evaluation under constrained conditions showed performance degradation with increasing the number of relay terminals. Second, in multiple-RRU environment, we found that the proposed scheme achieved a maximum transmission capacity of approximately 25% improvement over the conventional scheme in the distributed MIMO environment.

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