Postprint of IDNC Cooperative Retransmission Scheme Based on Device Heterogeneity and D2D Networks

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Abstract

To satisfy the personalized requirements of end users and reduce the transmission delay in D2D networks, a cooperative retransmission scheme based on instantly decodable network coding (IDNC) with terminal differentiation is proposed. First, this scheme introduces a novel IDNC algorithmic framework to address the decoding conflicts and transmission conflicts inherent in PC-D2D networks, and searches for maximal independent sets (MIS) based on this framework. It comprehensively considers packet reception status, terminal user demands, and link packet loss rates to design weights, and evaluates these weights to select concurrent cooperative retransmitting terminals and packet combinations that generate coded packets with the minimum incremental delay per retransmission. Simultaneously, by considering future decoding opportunities provided by unwanted packets, the scheme optimizes the unwanted packets at terminals to further reduce transmission delay. Simulation results demonstrate that the proposed scheme can effectively reduce decoding delay and completion time while satisfying the personalized requirements of terminals.

Full Text

Preamble

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IDNC Cooperative Retransmission Scheme Based on Terminal Differentiation and D2D Networks

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Abstract: To meet the personalized needs of end users and reduce transmission delay in D2D networks, this paper proposes an Instantly Decodable Network Coding (IDNC) cooperative retransmission scheme based on terminal differentiation. First, the scheme introduces a novel IDNC algorithmic framework to address decoding and transmission conflicts in PC-D2D networks, and searches for maximal independent sets (MIS) within this framework. The design incorporates weights that comprehensively consider packet reception status, terminal user requirements, and link loss rates to select concurrent cooperative retransmission terminals and packet combinations that minimize the incremental delay per retransmission. Simultaneously, by considering future decoding opportunities provided by unnecessary packets, the scheme optimizes packets not needed by terminals to further reduce transmission delay. Simulation results demonstrate that the proposed scheme effectively reduces decoding delay and completion time while satisfying personalized terminal requirements.

Keywords: D2D; Instantly Decodable Network Coding; cooperative retransmission; decoding conflict; transmission conflict; terminal differentiation

0 Introduction

With the explosive growth of data, user traffic demand is increasing exponentially. Device-to-Device (D2D) communication has emerged as a method to enhance communication capacity and reduce backhaul traffic [1]. Through D2D communication, transmitting devices can directly communicate with other devices in close proximity without requiring a base station (BS). D2D communication has been widely adopted due to its significant advantages in reducing bandwidth and energy consumption on backhaul links.

In 2000, Ahlswede et al. [2] introduced Network Coding (NC), which transformed the traditional store-and-forward paradigm at intermediate nodes. Network coding allows intermediate nodes to encode and forward packets according to specific rules, substantially reducing system transmission delay and the number of transmissions. Instantly Decodable Network Coding (IDNC) [3–9], as a subclass of XOR-based coding, has long been recognized as a promising technology, particularly for reducing delay and increasing throughput. IDNC, as an instant decoding technique, is widely used in real-time applications, and the simplicity of using XOR binary operations for encoding and decoding files is well-suited for battery-constrained terminal devices [10–13].

Numerous scholars have long investigated the application of IDNC in D2D networks to reduce packet retransmissions and minimize completion delay. The Heuristic Maximum Clique IDNC (HMC-IDNC) algorithm in [14] considers adjacency degree, always adding the vertex with maximum adjacency degree to select the maximum clique. The Minimum Relevancy Clique IDNC (MRC-

IDNC) algorithm in [15] also considers adjacency degree but adds the vertex with minimum adjacency degree to preserve future coding opportunities. Reference [16] considers link loss rates, adding vertices with the lowest loss rates to select the maximum clique. Reference [17] comprehensively considers channel quality, terminal energy, stability, and other factors, designing the MWP-QE algorithm that always adds the vertex with maximum residual energy to select the maximum clique.

However, subsequent research revealed that limited transmission power prevents direct communication between every terminal, prompting many scholars to focus on Partially Connected D2D (PC-D2D) networks [6,14,15]. Early PC-D2D research defined the minimization of decoding delay or completion time as the number of transmissions required before all users obtain their desired packets, assuming all users were interested in the same set of packets. In reality, however, users may have different interests in packets, reflecting varying traffic demands that manifest as different packet requirements. Data is transmitted in packets, with each packet transmitted within a fixed duration to satisfy terminal user needs. Addressing this reality, this paper proposes an IDNC cooperative retransmission scheme based on terminal differentiation and D2D networks (CRTD). During the retransmission phase, the scheme considers terminal requirements, link loss rates, and packet reception status, employing a novel IDNC algorithmic framework to avoid transmission and coding conflicts in PC-D2D networks. It searches for maximal independent sets to generate concurrent cooperative retransmission devices and encoded packets with minimal incremental delay per retransmission. Simultaneously, by optimizing packets not needed by terminals, the scheme further reduces transmission delay.

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1 System Model and Definitions

1.1 System Model

As shown in Figure 1, the PC-D2D network model comprises one base station and N terminals. The base station V broadcasts a file consisting of M packets to N terminals, where the file set is $\mathcal{P} = \{p_1, p_2, \dots, p_M\}$ and the receiver user set is $\mathcal{I} = \{R_1, R_2, \dots, R_N\}$. Each terminal R_i has its unique set of required packets $\mathcal{W}_i \subseteq \mathcal{P}$. The link loss rate from the base station to each terminal is $P_{i,V}$, and the file consists of M packets.

The data transmission model comprises two phases: the initial phase and the retransmission phase. In the initial phase, the base station broadcasts packets to terminals. Since this phase considers different required packets per terminal, terminals do not receive unnecessary packets, which could cause decoding failures. Therefore, terminal differentiation is not considered in this phase, and each terminal can overhear packets it does not need. The set of packets overheard by terminal R_i is denoted as $\mathcal{O}_i$.

After the base station' s broadcast, each receiver may be in one of three situations:

a) **Received packet set** $\mathcal{H}_i$: The set of packets already received by receiver R_i, where $\mathcal{H}_i = \mathcal{H}_i^u \cup \mathcal{H}_i^o$. Here, $\mathcal{H}_i^u$ represents the set of needed packets received by R_i, and $\mathcal{H}_i^o$ represents the set of unneeded packets received by R_i. Clearly, $\mathcal{H}_i^u \cap \mathcal{H}_i^o = \emptyset$.

b) **Missing packet set** $\mathcal{L}_i$: The set of packets lost by receiver R_i.

c) **Required packet set** $\mathcal{R}_i$: The set of needed packets lost by receiver R_i, where $\mathcal{R}_i = \mathcal{W}_i \setminus \mathcal{H}_i^u$.

The following constraints apply: $\forall p \in \mathcal{P}, \exists i \in \mathcal{I} : p \in \mathcal{H}_i$, meaning each packet must be successfully received by at least one device. If a packet is not received by any terminal, it must be retransmitted from the base station. Additionally, if all users have received a particular packet, that packet is removed from the packet set.

In the second phase, the base station authorizes spectrum for D2D users, who exchange packets to recover their required packets. Assuming users are in close proximity within the same transmission range, they can connect via WiFi, Bluetooth, or other D2D links. The link loss rate from terminal R_i to terminal R_j is denoted as $P_{i,j}$.

1.2 Key Definitions

Definition 1 (Partially Connected D2D Network, PC-D2D). A network where device R_i can directly connect to device R_j (single-hop) if $P_{i,j} < 1$. If communication occurs through an intermediate device R_k, it is considered multi-hop.

Definition 2 (State Feedback Matrix, SFM). A matrix formed when receivers feed back their packet reception status to the base station via ACK/NACK messages. As shown in Equation (1):

$$S_{i,k} = \begin{cases} 1 & \text{if } p_k \in \mathcal{H}_i \\ -1 & \text{if } p_k \in \mathcal{R}_i \\ 0 & \text{if } p_k \in \mathcal{O}_i \end{cases}$$

Definition 3 (System Connection Matrix, SCM). A matrix storing packet reception probabilities between all devices, defined as $C_{i,j} = 1 - P_{i,j}$.

Definition 4 (Coverage Area). $\mathcal{C}_i$ represents the set of devices that device R_i can connect to via erasure channels.

Definition 5 (Decoding Delay, DD). When receiver R_i receives an IDNC-encoded packet at time t, three cases exist for terminal decoding:

- **Undecodable packet**: $|\mathcal{R}_i \cap \mathcal{X}| = 0$, where the encoded packet contains no packets needed by the terminal.
- **Instantly decodable packet**: $|\mathcal{R}_i \cap \mathcal{X}| = 1$, containing exactly one needed packet.
- **Non-instantly decodable packet**: $|\mathcal{R}_i \cap \mathcal{X}| \geq 2$, containing multiple needed packets.

Decoding delay increases by one unit when undecodable or non-instantly decodable packets are received, or when packets are lost, expressed as $d_i(t) = 1$.

Definition 6 (Individual Completion Delay, ICD). The total time for terminal R_i with non-empty requirement set to decode all required packets at any time m, expressed as $ICD_i = \sum_{t=1}^{T_i} d_i(t)$.

Definition 7 (Completion Delay, CD). The total transmission time for all terminals with non-empty requirement sets to obtain all required packets, expressed as $CD = \sum_{i=1}^{N} ICD_i$.

The symbols and their meanings used throughout this paper are summarized in Table 1.

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2 IDNC-Based Cooperative Retransmission Scheme for Terminal Differentiation

In PC-D2D networks, limited terminal coverage prevents all terminals from directly exchanging packets. When two different transmitting devices simultaneously send packets or encoded packets to the same receiving device within their coverage areas, transmission conflicts occur. Similarly, decoding conflicts arise when terminals receive encoded packets. We illustrate this with an example.

As shown in Figure 2, the scenario consists of two transmitting devices and five terminals with different data sets. When transmitting device s_1 sends packet p_1 to receiving device R_3, and transmitting device s_2 sends packet p_2 to receiving device R_3, packet loss occurs due to imperfect channels. Terminals fail to obtain all required packets, necessitating retransmission. Receivers first feed back packet reception status to transmitters, which form their respective state feedback matrices. Based on this feedback, transmitters select encoding schemes: Terminal R_1 can decode its required packet p_3 via XOR operations on packets p_1 and p_2, and terminal R_2 can similarly decode p_4. However, when both encoded packets $p_1 \oplus p_2$ and $p_1 \oplus p_4$ are transmitted simultaneously to terminal R_3, R_3 can only decode one, resulting in a transmission conflict (Figure 3).

This section proposes a novel IDNC framework to address these issues, introducing two key definitions:

Definition 8 (Decoding Conflict, DC). Occurs when an encoded packet sent by a transmitter cannot enable a terminal to obtain its required packets.

Definition 9 (Transmission Conflict, TC). Occurs when transmitting devices s_i and s_j simultaneously transmit packets or encoded packets to receiving device R_k, causing collisions.

2.1 IDNC Graph Framework Design

The IDNC graph model represents transmission relationships between devices and encoding relationships among missing packets at terminals. This framework comprises two components: local sending matrix construction and vertex connection condition establishment.

2.1.1 Local Sending Matrix Construction Based on the state feedback matrix at each time slot t, we generate a Local Sending Matrix (LSM) according to the following definition:

Definition 10 (Local State Matrix, LSM). For each device R_i acting as a sender, the matrix rows and columns represent the sender' s coverage device set and its possessed packet set, respectively. Vertices are generated from the LSM as $v_{i,l,k}$, where i denotes the specific sending device, l denotes the packet to be sent, and k denotes the target terminal. The vertex corresponds to the position of 1 in the LSM.

2.1.2 Vertex Connection Conditions Considering decoding conflicts at receivers and transmission conflicts under simultaneous same-frequency transmission, we design the following connection conditions:

1. **Decoding conflict within same device**: $\exists R_i \in \mathcal{I}, p_l, p_m \in \mathcal{P} : R_i$ loses different packets p_l, p_m, preventing terminal acquisition of required packets in this transmission.
2. **Decoding conflict across devices**: $\exists R_i, R_j, R_k \in \mathcal{I}, p_l, p_m \in \mathcal{P} : R_i, R_j$ lose two different packets, but at least one device does not possess a packet needed by the other, causing decoding conflict.
3. **Transmission conflict to same receiver**: $\exists R_i, R_j, R_k \in \mathcal{I}, p_l, p_m \in \mathcal{P}$: Different transmitting devices R_i, R_j simultaneously transmit packets to terminal R_k, and R_k is in the joint coverage area of the transmitters.
4. **Transmission conflict across receivers**: $\exists R_i, R_j, R_k, R_m \in \mathcal{I}, p_l, p_m \in \mathcal{P}$: Different transmitting devices R_i, R_j transmit packets to different receiving devices R_k, R_m, but at least one of R_k or R_m is in the joint coverage area of the transmitters, or one transmitter is the target of another.

2.2 One-Layer IDNC Graph

2.2.1 Overview Due to terminal heterogeneity, user requirements also differ, manifested by varying packet demands. This section designs a one-layer IDNC graph based on the novel IDNC framework and user requirements.

Definition 11 (One-Layer IDNC Graph, ALIDNC). A graph model representing transmission relationships between devices and encoding relationships among required packets. Vertices generated when a sender' s unneeded packets satisfy the receiver' s LSM are marked with x.

Based on Definition 2, the base station forms SFM and SCM matrices, then generates LSMs for each device as a sender. Since retransmitted packets must satisfy terminal demands, we exclude steps where non-required packets could benefit terminals, as shown in Example 2.

Assume the state feedback matrix and connection matrix fed back to the base station are:

$$S = \begin{pmatrix} 1 & 0 & 2 \\ 1 & 0 & 1 \\ 0 & 0 & 1 \end{pmatrix}, \quad Y = \begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \end{pmatrix}$$

The resulting local sending matrices are:

$$LSM_1 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}, \quad LSM_2 = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}, \quad LSM_3 = \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$$

The one-layer IDNC graph is shown in Figure 4.

2.2.2 Vertex Weight Design for One-Layer IDNC Considering the decodability of transmitted encoded packets at terminals, we introduce the vertex weight expression from [16]:

$$w(v_{i,l,k}) = \sum_{\substack{R_j \in \mathcal{I} \\ R_j \neq R_i}} \sum_{\substack{p_n \in \mathcal{R}j \\ p_n \neq p_l}} \left[T(p_l, p_n) \cdot \mathbb{I}(|\mathcal{R}_j \cap \{p_l, p_n\}| = 1)\right] - \sum_{R_j \in \mathcal{I}} \mathbb{I}(|\mathcal{R}_j \cap \{p_l\}| = 0)$$

Equation (8) comprehensively considers: the number of target terminals for the sender, cases where receivers cannot obtain required packets from received encoded packets, and cases where terminals can benefit from lost encoded packets during transmission.

2.2.3 Selection of Cooperative Retransmission Devices and Encoded Packets Based on the connection conditions, vertices from the LSM are connected. The maximal independent set (MIS) with the highest weight represents the optimal retransmission scheme without transmission or coding conflicts:

$$\mathcal{M}^* = \arg\max_{\mathcal{M} \in \mathcal{G}} \sum_{v \in \mathcal{M}} w(v)$$

The selected MIS may yield several cases: 1. If $\mathcal{M} = \{v_{i,l,k}\}$, the retransmission scheme is: sender R_i transmits packet p_l to receiver R_k. 2. If $\mathcal{M} = \{v_{i,l,k}, v_{m,n,j}\}$, the scheme involves simultaneous transmissions from R_i to R_k and R_m to R_j. 3. If $\mathcal{M} = \{v_{i,l,k}, v_{m,n,j}, v_{x,y,z}\}$, three simultaneous transmissions occur.

2.3 Two-Layer IDNC Graph Based on Future Decoding Opportunities

2.3.1 Decoding Benefit of Unneeded Packets The ALIDNC graph only considers decoding conflicts, transmission conflicts, and beneficial required packets. This section explores future decoding opportunities provided by unneeded packets to optimize resource utilization. The relationship between unneeded packet p_j and terminal R_i has two cases:

1. **Case (1)**: $\forall R_i \in \mathcal{I}, p_j \notin \mathcal{W}_i$, meaning no terminal needs packet p_j.
2. **Case (2)**: Packet p_j is needed by at least one terminal R_k, and this terminal possesses at least one packet from R_i' s requirement set.

In Case (1), p_j cannot provide future decoding opportunities and is termed a *useless packet*. In Case (2), the unneeded packet can provide future decoding opportunities.

2.3.2 Vertex Weight Design for Two-Layer IDNC For the two-layer IDNC graph, we introduce weights for unneeded packets providing future decoding opportunities in multicast scenarios [17]:

$$w(v_{i,l,k}) = \sum_{\substack{R_j \in \mathcal{I} \\ R_j \neq R_i}} \sum_{\substack{p_n \in \mathcal{R}j \\ p_n \neq p_l}} \left[T(p_l, p_n) \cdot \mathbb{I}(|\mathcal{R}_j \cap \{p_l, p_n\}| = 1)\right] + \sum_{\substack{R_n \in \mathcal{I} \\ R_n \neq R_i}} \sum_{p_o \in \mathcal{O}n} \kappa_{i,j,n} \cdot (1 - P_{i,j}) \cdot (1 - P_{n,k})$$

Inspired by terminal differentiation and partial connectivity, Equation (12) modifies the weight design to:

$$w(v_{i,l,k}) = \sum_{\substack{R_j \in \mathcal{I} \\ R_j \neq R_i}} \sum_{\substack{p_n \in \mathcal{R}j \\ p_n \neq p_l}} \left[T(p_l, p_n) \cdot \mathbb{I}(|\mathcal{R}_j \cap \{p_l, p_n\}| = 1)\right] + \sum_{\substack{R_n \in \mathcal{I} \\ R_n \neq R_i}} \sum_{p_o \in \mathcal{O}n} \alpha_{i,j,n} \cdot \kappa_{i,j,n} \cdot (1 - P_{i,j}) \cdot (1 - P_{n,k})$$

where $\alpha_{i,j,n}$ and $\kappa_{i,j,n}$ are binary variables set to 1 when Case (2) is satisfied.

2.3.3 Retransmission Strategy Selection When selecting the optimal conflict-free retransmission scheme, two scenarios emerge:

Scheme 1: Selects the MIS from the ALIDNC graph, satisfying only terminal user requirements without optimizing unneeded packets. The weight is $w_1(v_{i,l,k})$.

Scheme 2: Selects the MIS from both ALIDNC and CIDNC graphs, satisfying requirements while optimizing unneeded packets. The weight is $w_2(v_{i,l,k})$.

The optimal scheme is selected by comparing weights:

$$\text{If} \sum_{v \in \mathcal{M}_{\text{ALIDNC}}} w_1(v) > \sum_{v \in \mathcal{M}_{\text{CIDNC}}} w_2(v), \text{ choose Scheme 1; otherwise, choose Scheme 2.}$$

Definition 12 (Two-Layer IDNC Graph, SEIDNC). A graph model representing transmission relationships and encoding relationships among unneeded packets. Vertices generated when a sender's required packets satisfy the receiver' s LSM are marked with x.

Definition 13 (Comprehensive IDNC Graph, CIDNC). The union of one-layer and two-layer IDNC graphs.

Continuing Example 2 and considering future decoding opportunities from unneeded packets, the comprehensive IDNC graph is shown in Figure 5. The retransmission strategy selects the maximum-weight independent set from both the one-layer IDNC graph (Figure 4) and the comprehensive IDNC graph (Figure 5), then chooses the optimal scheme.

2.4 Cooperative Retransmission Procedure

Step 1: Receivers feed back reception and connection status to the base station, which constructs SFM and SCM matrices.

Step 2: Build local sending matrices for each user as a sender, and construct the one-layer IDNC graph $\mathcal{G}_1(V, E)$ where vertices correspond to schemes satisfying terminal requirements without conflicts.

Step 3: Select the independent set with maximum weight in $\mathcal{G}_1$.

Step 4: Check if any receiver' s requirement set is empty; if not, exclude it from $\mathcal{G}_2$ construction. Determine if unneeded packets can provide future decoding opportunities. If not, the maximum-weight independent set in $\mathcal{G}_1$ is optimal. If yes, proceed to Step 5.

Step 5: Build the two-layer IDNC graph $\mathcal{G}_2$ and combine it with $\mathcal{G}_1$ to form the comprehensive IDNC graph $\mathcal{G}_c$. Calculate weights and select the maximum-weight independent set.

Step 6: Compare the maximum weights from $\mathcal{G}_1$ and $\mathcal{G}_c$, selecting the scheme corresponding to the larger weight as the optimal conflict-free retransmission strategy.

Step 7: The base station selects a set of senders and their packet combinations using the IDNC algorithm and notifies all terminals of the transmission and encoding strategy.

Step 8: Senders transmit encoded packets. Receivers decode to obtain required packets and feed back reception status. The base station updates SFM and repeats Steps 1–8 until all terminals obtain their required packets.

The flowchart for one cooperative retransmission is shown in Figure 6.

2.5 Algorithm Complexity Analysis

In the CRTD strategy, the complexity to generate terminal R_i' s local sending matrix is $\mathcal{O}(|\mathcal{C}_i| \cdot |\mathcal{H}_i|)$. For all terminals, this becomes $\mathcal{O}(\sum_{i=1}^{N} |\mathcal{C}_i| \cdot |\mathcal{H}_i|)$. Building vertices for required packets has complexity $\mathcal{O}(N \cdot M)$, while building vertices for missing packets has complexity $\mathcal{O}(N^2 \cdot M)$. Searching for the maximal independent set in a graph with $|V|$ vertices has complexity $\mathcal{O}(|V|^3)$. Therefore, the overall CRTD complexity is:

$$\mathcal{O}\left(\max\left\{\sum_{i=1}^{N} |\mathcal{C}_i| \cdot |\mathcal{H}_i|, N^2 M, |V|^3\right\}\right) = \mathcal{O}(N^2 M)$$

3 Simulation Analysis

Simulations were conducted using OPNET Modeler 14.5, comparing CRTD against: (1) Completion Time Reduction for Partially Connected D2D Enabled Network using Binary Codes (CTRBC) [15], and (2) Data Dissemination using Instantly Decodable Binary Codes in Fog-Radio Access Networks (DDAC) [16]. The comparison highlights CRTD' s advantages in meeting user requirements while reducing completion delay, decoding delay, and improving coding gain.

3.1 Simulation Setup

The simulation considers a PC-D2D network with devices randomly distributed in a 500m hexagonal cell. D2D devices connect via WiFi or Bluetooth links. The model includes one base station V and N terminals. After the base station' s initial broadcast, each user receives some packets and loses some desired packets due to erasure channel losses. Short-range D2D links are assumed more reliable than base station communications, with device-to-device erasure probabilities set to half of base station-to-device probabilities. The ratio of non-empty requirement neighboring devices to total devices is defined as G, set to $G = 0.3$. Simulation parameters are listed in Table 2.

Table 2: Simulation Parameter Settings

Parameter	Value
Base station coverage (m)	500
BS-to-terminal loss rate	[0.2, 0.4, 0.6, 0.8, 1]
Inter-device loss rate	0.5 × BS-to-terminal rate

Parameter	Value
Number of packets	[10, 15, 20, 25, 30]
Simulation time (s)	1000
Transmission rate (kbps)	128, 528, 828
Number of terminals	[10, 15, 20, 25, 30]
Random seed	Multiple values
Proportion of unneeded packets	0.3

3.2 Simulation Results

Figures 7 and 8 show performance with $N = 30$, $M = 20$, $P_{i,V} = 0.3$, and $P_{i,j} = 0.15$. Results demonstrate that CRTD significantly reduces overhead in low-connectivity PC-D2D networks, while CTRBC and DDAC show limited improvement in average completion time. CTRBC only considers inter-sender cooperation without addressing potential conflicts, and DDAC considers multi-device collision but neglects realistic user differentiation. CRTD improves upon DDAC by designing a conflict-aware IDNC framework focused on realistic user demand differences, considering terminal decoding status and optimizing unneeded packets. Particularly when network connectivity $G = 0.3 \sim 0.6$, CRTD markedly reduces average decoding delay and retransmissions while improving transmission efficiency.

Figures 9 and 10 show average completion time versus terminal count (with $M = 15$) and packet count (with $N = 15$) at $G = 0.4$. Results indicate that completion time increases with both metrics. Since CTRBC and DDAC only optimize needed packets while ignoring unneeded ones, CRTD' s optimization provides better decoding opportunities for future transmissions, demonstrating clear advantages in reducing completion time.

Figures 11 and 12 show average decoding delay versus terminal count ($M = 15$) and packet count ($N = 15$) at $G = 0.4$. Trends mirror completion time results, with CRTD exhibiting slower delay growth compared to alternatives, confirming its superiority in reducing average decoding delay.

4 Conclusion

This paper proposes a CRTD scheme for PC-D2D networks that introduces a novel IDNC framework addressing transmission and decoding conflicts. The scheme constructs one-layer and two-layer IDNC graphs to satisfy terminal requirements while optimizing unneeded packets. By comprehensively evaluating transmission strategies, CRTD meets personalized user needs. Simulation results demonstrate that CRTD effectively reduces completion time, decoding delay, and retransmission count, providing a solution for reducing PC-D2D delay and satisfying terminal user personalization. Future work will expand beyond demand differentiation to consider terminal processing capability, residual energy, bandwidth, and other heterogeneous factors to further optimize network performance.

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Note: Figure translations are in progress. See original paper for figures.