RANC: Relay-Aided Network-Coded D2D Network

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***Abstract*—This paper studies an approach towards employing network coding in device-to-device (D2D) network. In a D2D network, the devices in proximity establish direct links for communication instead of utilizing the cellular links. In this paper, relay-aided network-coded (RANC) D2D network is compared with a simple relay-aided D2D network. A D2D network with three source-destination pairs aided by a relay is considered for analysis. The transmissions are directed according to the priorities assigned to D2D pairs on the basis of channel characteristics, i.e., the links suffering from channel degradation are assigned higher priority. Two scenarios are studied; a D2D network with path loss and a D2D network without path loss. End-to-end success probability is quantified for RANC and simple relay-aided D2D network with respect to a signal-to-noise ratio (SNR) margin.**

I. Introduction

The demand for higher data rates and reliable communication networks prompted the need for the introduction of fourth generation (4G) communication technology. Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE) wireless communication standards were developed under the aegis of 4G communication networks, providing data services including internet access to mobile user equipments (MUEs). Compared to 2015, the global mobile data traffic is expected to grow 478% by 2019 [1]. 5G technology has received significant attention as a futuristic standard for high data rate peer-to-peer (P2P) links.

One of the main objectives of 5G is to develop a network, which connects wireless devices on a massive scale with much faster data rates and very low latency. This could open up several avenues of research and practical applications. The cooperative communication among devices provides reliability and diversity in the network, which is quite useful in situations where sensitive data is being shared. The future holds great prospects for research on 5G and its allied technologies, which include device-to-device networks (D2D), machine-to-machine communications (M2M), heterogeneous networks (HetNets) and internet of things (IoT) among others [2].

D2D is a technology associated with LTE-Advanced (Long Term Evolution Advanced), which forms a part of the 3rd Generation Partnership Project (3GPP) Release. 12. Instead of resorting to cellular links, direct links between devices are exploited for providing proximity and diversity gains. Proximity-based services are a distinctive feature of D2D networks [3]. The concept of offloading traffic from cellular network is envisioned in 5G networks. D2D networks aid the base station (BS) in providing services such as live video sharing [4].

D2D networks promise enhanced system performance but also pose some challenges which need to be addressed. In [5], the authors discuss interference management especially in environments where D2D network coexists with cellular deployments involving macrocells and femtocells. Efficient resource allocation scheme is discussed in [6], highlighting the need for conservation of resources. Similarly, [7] explains the importance of network discovery due to mobility of D2D users. Interference signals can be exploited to provide D2D network security by blocking the eavesdropping nodes with the help of interference signals [8]. Network coding (NC) in D2D networks has been explored as a possible technique for increasing network reliability by providing diversity [9].

The rest of the paper is organized as follows. In Section II, an overview of the network coding techniques in D2D networks is presented. Section III highlights the system model and defines the network coding technique along with transmission flow. Results are presented in Section IV, followed by conclusion at the end.

II. Related Work

D2D networks could exploit network coding to improve end-to-end data delivery. [10] explains the utility of NC in BS-assisted D2D networks. The proposed mode of operation consists of two D2D users, where BS acts as a relay. The D2D users transmit in the first two time slots, while the BS applies exclusive OR (XOR) operation and transmits in the third time slot. The results highlight enhanced network scalability.

Deviating from the concept of considering interference as an impairment, authors in [11] explain the utility of physical layer network coding (PNC), where interference is maneuvered in a positive manner. Electromagnetic waves undergo superimposition to form a code. In the first time slot, the D2D users share their messages with the relay. The relay applies PNC and transmits the coded message in the second time slot. Traditional two source relay network uses four time slots for exchanging information but PNC-assisted two source relay network exchanges information in two time slots, which enhances network capacity.

The authors in [12] highlight the use of NC in mobile cloud scenarios. Different D2D cluster topologies are discussed. The

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authors demonstrate diversity gains achieved through NC in scenarios where D2D node density is high. Furthermore, the utility of NC-assisted cooperative D2D is explored for live data transmission. Devices can cooperate by receiving chunks of desired data and then sharing the chunks cooperatively for complete download [13]. The proposed mechanism helps in conserving energy and avoiding delay in transmissions. Similarly, in [14] the gains achieved through joint NC and resource allocation in D2D communication networks are emphasized. Analysis of cumulative density function (CDF) of spectral efficiency and end-to-end signal-to- interference ratio (SINR) signify the enhanced performance of D2D networks. Authors conclude by asserting the utility of proposed scheme in future 5G D2D networks.

Authors in [15] discuss a relaying technique, where inactive nodes are identified and utilized as relays. NC complemented by optimal relay selection yields higher sum rates when compared to traditional D2D communication networks. In [16], the authors highlight the benefits of NC-assisted D2D communication networks combined with caching techniques for proximity services in the context of future 5G communication networks. The proposed scheme is especially useful in scenarios where several D2D users demand similar contents.

In [17] a comparison is presented between traditional D2D communication network, D2D aided by analog NC and D2D aided by space-time analog network coding (STANC). The proposed topology consists of three D2D pairs with a two antenna relay, which amplifies and forwards the received signals. Zero forcing detection takes place at the receiver to recover the desired information. Average sum rate versus SNR is analyzed, which reveals the benefits of STANC over other techniques.

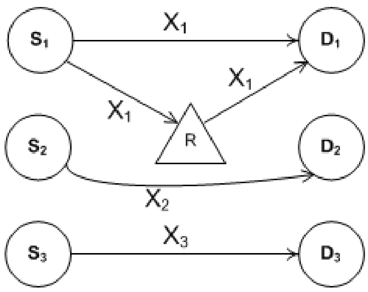


Fig. 1. Relay aided 3-D2D pair network

III. System Model

In this section, we illustrate the system level topology of our network. Fig. 1 explains the deployment of D2D source-destination pairs aided by a relay. Source S_1 transmits in the first time slot, followed by S_2 and S_3 in the next two time slots. Final time slot is reserved for the transmission from relay R, which employs a decode and forward (DF) mechanism. We assume equal transmit power of all sources and the relay. A destination is able to successfully decode a message if the received signal-to-noise ratio (SNR) is above a predetermined threshold τ. In case, D2D pair i, $i \in \{1, 2, 3\}$ suffers from a weak link, the relay receives a copy of the information sent by source S_i and transmits it to destination D_i in the fourth time slot.

We compare the aforementioned relay-aided D2D network with a relay-aided network-coded (RANC) D2D network. Fig. 2 illustrates the proposed RANC scheme. Fig. 2(a) explains the transmission in the first time slot, where the source S_1 broadcasts its information. Moving on, the source S_2 employs NC to form a code $a_1X_1 + a_2X_2$ and broadcasts the coded information. The coefficients a_1 and a_2 are selected from a finite (Galois) field, forming linearly independent codewords. Similarly, S_3 broadcasts a code $a_3X_1 + a_4X_2 + a_5X_3$, in the third time slot. The fourth time slot is reserved for the transmission of network coded information by the relay. Multiple codewords are received at all the destinations in different time slots. The desired information can be recovered at the respective receiver by using a simple Gaussian elimination method.

The links between D2D source-destination pairs and relays are defined in Table I. Without loss of generality, we assume that link l_1 suffers from maximum channel degradation. The transmission flow highlighted in Fig. 2 is routed in a manner that supports the channel suffering from weakest link by providing diversity. For this case, we accord highest priority P_1 to D2D pair 1, where the destination D_1 can at most receive four codewords containing transmitted message X_1. Similarly, D_2 and D_3 are accorded priority P_2 and P_3, respectively. The transmission flow could be manipulated dynamically according to the channel state information. If, at a later stage, D2D pair 3 suffers from the weakest link then it could be accorded priority P_1, thereby directing transmission flow for enhancing reliability. Priority could also be assigned on the basis of the sensitivity of the transmissions. The node sharing the most sensitive information could demand for a higher priority.

Let $\mathbb{I}_{l_i}$ is a binary indicator random variable (RV) describing the link status such that

$$\mathbb{I}_{li} = \begin{cases} 0 & \text{if link } l_i \text{ is successful} \\ 1 & \text{if link } l_i \text{ fails.} \end{cases} \quad (1)$$

The notion that a link is successful can be described by comparing the received SNR of that link with a predefined threshold. In this case, the SNR is defined as

$$SNR_{l_i} = \frac{P_t \mu_{l_i}}{d_{l_i}^{\beta} \sigma^2}, \quad (2)$$

where P_t is the transmit power, μ_{l_i} denotes the exponential channel gain corresponding to Rayleigh fading at distance d with path loss exponent β and σ^2 denotes the noise power. If the received SNR_{l_i} is greater than τ, the link is considered successful and vice versa. The success probability of a link is denoted by

$$P_s^{(l_i)} = \mathbb{P}\{SNR_{l_i} \geq \tau\} = exp^{-\tau d_{l_i}^{\beta}}. \quad (3)$$

TABLE I
D2D LINKS

D2D Pair	S_1-D_1	S_1-S_2	S_2-D_1	S_1-S_3	S_2-S_3	S_3-D_1	S_1-R	S_2-R	S_3-R	$R-D_1$
Link	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}

We assume unit transmit power for all transmitters and consider σ^2=1 for all links.

When all transmissions are completed, the indicator RVs form a binary set $\mathcal{X}$, which is represented by

$$\mathcal{X} = [\mathbb{I}_{l1}, \mathbb{I}_{l2}, \cdots, \mathbb{I}_{l_{10}}]\,. \tag{4}$$

An outage event can then be classified given the event $\mathcal{X}$, where $P_o^{(l_i)} = 1 - P_s^{(l_i)}$; $P_o^{(l_i)}$ denotes the link outage of l_i.

If supposedly, one complete transmission realization yields a set $\mathcal{X} = \{0110101110\}$, we can ascertain the successful and unsuccessful links on the basis of the binary values. In this case, link $\mathbb{I}_{l_1}$ fails followed by success of $\mathbb{I}_{l_2}$ and so on.

For the given set $\mathcal{X}$ the probability that destination D_1 is not able to decode the messange transmitted by source S_1 is given as

$$P_{o|\mathcal{X}}^{(D_1)} = \prod_{m \in Y} P_o^{(m)} \prod_{n \in Z} P_s^{(n)} \tag{5}$$

where $Y = \{1, 4, 6, 10\}$ and $Z = \{2, 3, 5, 8, 9\}$ denotes the set of links in outage and success, respectively. Similarly, all the possibilities of outage of D_1 are considered from set $\mathcal{X}$ and added to find the total outage probability at D_1. The same method is followed for determining the total outage probabilities of D_2 and D_3.

IV. Results and Analysis

In this section, we present our results and analyze the system performance. We compare the simple relay-aided D2D network with RANC in order to ascertain the network deployment, which best suits the requirements from a designer perspective. In our analysis, we define a normalized parameter SNR margin, γ, given as

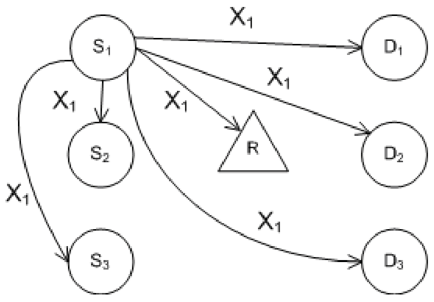
$$\gamma = \frac{P_t}{d^{\beta}\tau}. \tag{6}$$

Fig. 3 highlights the behavior of RANC and simple relay aided D2D network with respect to SNR margin. Priority P_1 is accorded to D2D pair 1. The success probability is calculated using (3) where $\beta = 2$. Two different scenarios are analyzed:

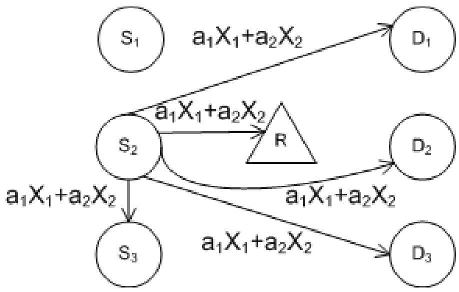
1) Network topology without path loss.
2) Network topology with path loss shown in Fig. 4.

If we observe at a particular SNR margin, e.g., 15dB, we can ascertain the performance of each topology. RANC outperforms the simple relay-aided D2D in both scenarios. Similarly, the topologies can be analyzed in different SNR margin regions and deployed according to their utility in terms of success probability.

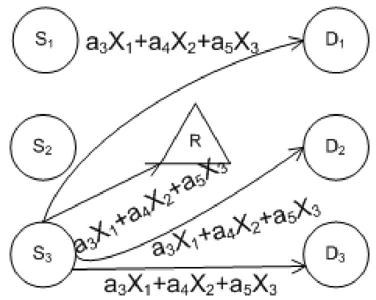
Table II highlights the system performance of RANC D2D over the simple relay-aided D2D for different SNR margins in terms of percentages calculated using (7), where $P_{s_{RANC}}^{D_i}$ and $P_{s_{relay-aided}}^{D_i}$ denote the success probabilities of RANC and



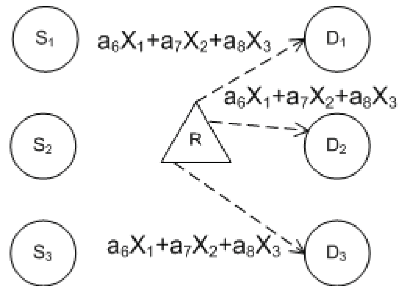
(a) Relay aided NC at time slot 1



(b) Relay aided NC at time slot 2



(c) Relay aided NC at time slot 3



(d) Relay aided NC at time slot 4

Fig. 2. Transmission pattern of relay-aided-network-coded (RANC) D2D

simple relay-aided D2D network for destination D_i, respectively. The negative values of percentage signify deterioration of RANC's performance when compared to simple relay-aided D2D while the positive sign signifies enhanced performance of RANC.

$$\%age = \frac{P_{s_{RANC}}^{D_i} - P_{s_{relay-aided}}^{D_i}}{P_{s_{relay-aided}}^{D_i}} \times 100. \tag{7}$$

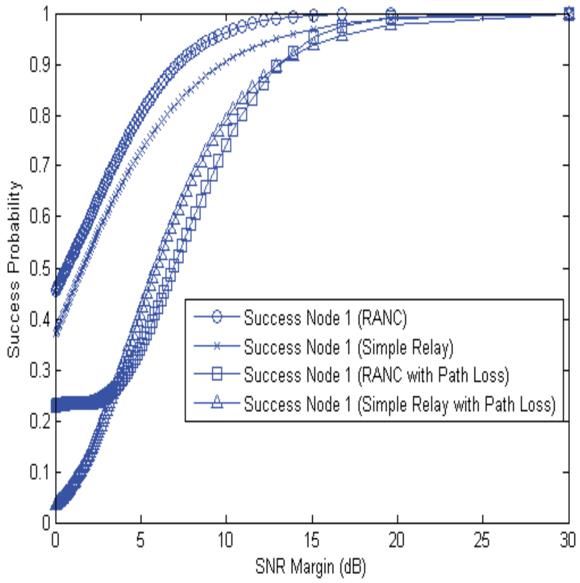


Fig. 3. Behavior of success probability for D2D pair 1

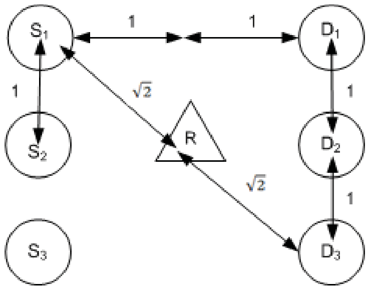


Fig. 4. Network topology with path loss distance.

Furthermore, the performance of D2D pair 1 is analyzed where link l_1 suffers from different fading characteristics. λ characterizes the mean of the exponential RV (corresponding to Rayleigh fading). We vary fading characteristics by considering different values of λ, where $\lambda = 0.2$ represents strongest fading. It can be seen that RANC outperforms simple relay-aided D2D network at higher SNR margins.

Similarly, the system performance for a scenario with path loss is presented in Table III. The table highlights the utility of RANC D2D network when a particular link suffers from channel degradation. Priorities could be assigned dynamically according to the channel characteristics. On the other hand, the simple relay-aided D2D network performs better in the SNR margin range of 10dB to 15dB.

The results show that the performance of RANC and simple relay-aided D2D network varies with respect to parameters such as SNR margins and path loss. The results also highlight the SNR margin operation regions where the aforementioned network topologies exhibit enhanced performance. Moreover, adverse channel conditions are maneuvered by employing RANC to provide network diversity.

TABLE II
PERFORMANCE OF RANC D2D WITH SIMPLE RELAY-AIDED D2D(WITHOUT PATH LOSS)

SNR margin(dB)	0	10	15	20	25	30
D2D Pair 1	23.60%	6.56%	2.75%	0.95%	0.31%	0.1%
D2D Pair 2	-17.71%	3.88%	2.4%	0.92%	0.30%	0.09%
D2D Pair 3	-4.81%	1.81%	-4.23%	0.06%	0.21%	0.09%
λ=0.2, D2D Pair 1	29.28%	8.83%	3.03%	0.98%	0.31%	0.09%
λ=0.4, D2D Pair 1	28%	8.2%	2.9%	0.90%	0.31%	0.09%
λ=0.6, D2D Pair 1	26.6%	7.67%	2.89%	0.97%	0.30%	0.09%
λ=0.8, D2D Pair 1	25.18%	7.11%	2.82%	0.96%	0.30%	0.09%

TABLE III
PERFORMANCE OF RANC D2D WITH SIMPLE RELAY-AIDED D2D(WITH PATH LOSS)

SNR margin(dB)	0	10	15	20	25	30
D2D Pair 1	572%	-6.14%	1.58%	1.4%	0.56%	0.19%
D2D Pair 2	1258%	-3.39%	5.15%	3.08%	1.16%	0.39%
D2D Pair 3	470%	-2.61%	5.29%	3.10%	1.16%	0.39%
λ=0.2, D2D Pair 1	39.58%	12%	5.16%	1.86%	0.61%	0.19%
λ=0.4, D2D Pair 1	93.73%	7.27%	4.23%	1.74%	0.60%	0.19%
λ=0.6, D2D Pair 1	196.05%	2.56%	3.33%	1.63%	0.59%	0.19%
λ=0.8, D2D Pair 1	361.02%	-1.90%	2.45%	1.52%	0.58%	0.19%

V. CONCLUSION

In this paper, we presented an approach towards employing network coding in D2D network. RANC scheme is compared with the relay-aided scheme to ascertain the utility of each technique. The Channel degradation is maneuvered by assigning priority to the D2D pairs suffering from weak links. The transmissions are directed in a manner such that diversity is provided to such links, thereby enhancing end-to-end transmission reliability. The results highlight the performance of both schemes with respect to SNR margin and path loss. From a designer perspective, SNR margin regions have been identified, quantifying success probability for RANC and simple relay-aided D2D network.

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