

Stability Analysis for Network Coded Multicast Cell with Opportunistic Relay

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Abstract—In this paper, we propose an opportunistic relay with network coding for multicast cell. Specifically, we propose three strategies for the opportunistic relay. By analyzing the stability regions for the three proposed strategies, we find that the two strategies with network coding outperform that without network coding in terms of stability region. In addition, the strategy with opportunistic network coding outperforms that with relatively static network coding. Finally, simulation results validate our theoretical predictions.

Index Terms—Multicast network, opportunistic relay, network coding, stability region.

I. INTRODUCTION

Cognitive radio network has been a new technology in wireless communication that improves utilization of limited spectral resources as the demand for wireless spectrum increases rapidly in recent years [1]. The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically [2], or in spectrum sharing [3]. A basic cognitive network with only one primary user and one secondary user has been investigated in [4], where the authors analyze the cognitive user's capacity without reducing the achievable rate of primary users in information-theoretic view. Joint physical and MAC layer analysis in cognitive radio network is considered in [5]. The authors demonstrate that the gains promised by cooperation at the physical layer can be leveraged to the MAC layer. The authors also address the stability region of the primary users in multiple access channel and delay analysis of the primary users.

Network coding is originally introduced to achieve the network multicast capacity in the wireline systems [6]. It has been extended to the wireless networks in [7] and [8]. In [9], the authors investigate the wireless multicast networks with regenerative network coding, and propose a power control scheme to achieve the full diversity. Most of these previous works on network coding assume that the source nodes always transmit packets. However, this is not always the case. For example, most of the sources in the wireless networks are bursty. Sometimes, they transmit data, while keep silent in some other times. Traffic dynamics at the primary user is considered in [10], where the activity of the primary user is modeled as Poisson process. The opportunistic spectrum access protocol is proposed in [11], where the secondary

user can use the free time slots when the primary user isn't transmitting. In [12], the authors investigate the power allocation schemes in cognitive radio networks with network coding. However, the authors did not analyze how cognitive users cooperate with the primary users. The authors did not yet analyze the network coding strategy in MAC layer or the QoS problems either.

In this paper, we leverage network coding in network coded multicast networks for system throughput improvement. When the packets from the source nodes are transmitted unsuccessfully to destinations, but successfully to the relay, the packets can be stored in the relay. But these packets have different types. Some are transmitted unsuccessfully to both destinations, and some are transmitted unsuccessfully to only one destination. In order to perform network coding, we should carefully schedule these packets to decide which packets can be network coded and which packets should be transmitted firstly.

In this paper, we will focus on the regenerative network coding where mixed signals are decoded at opportunistic relay and retransmitted to the destinations. We propose a dynamic network coding scheme, and demonstrate that our strategy with network coding can significantly improve throughput region compared to the strategy without network coding in the opportunistic relay of a multicast cell. In addition, the performance will be different for different strategies applied on the relay. Our contribution in this paper is: i) focusing on a physical layer view of the outage probability and applying an opportunistic relay protocol with network coding to a multicast cell, ii) investigating the QoS improvement and throughput of the multicast cell.

II. SYSTEM MODEL

We consider a multicast cell consisting of two users and an opportunistic relay node (see Fig. 1). The two source nodes are denoted by S_1 and S_2 , the two destination nodes are denoted by D_1 and D_2 , and the relay node is denoted by R . In our model, we assume that the relay consists of three queues R_0 , R_1 and R_2 . S_1 and S_2 transmit according to the TDMA protocol. Both source nodes need to broadcast information to both destinations successfully.

Each source node transmits one packet during one time slot sequentially. When the queue is empty, the time slot is

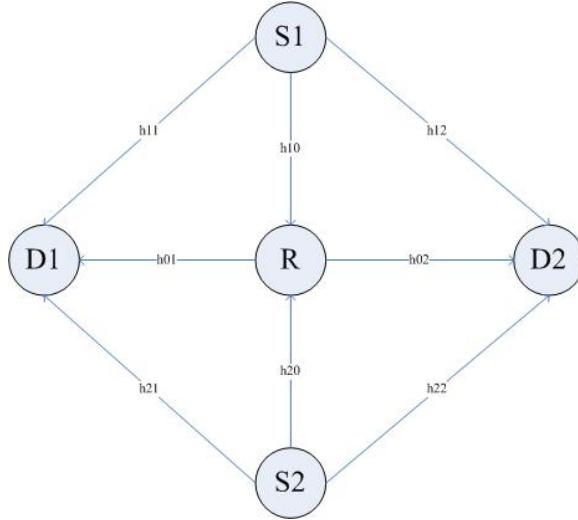


Fig. 1. The multicast cell with opportunistic network coded relay.

regarded to be free. When S_1 or S_2 transmits to D_1 , D_2 and R in one time slot, there are several transmission cases which are summarized in the following forms:

	1	2	3	4	5	6	7	8
D_1	Y	Y	N	Y	N	N	Y	N
D_2	Y	Y	N	N	Y	N	N	Y
R	Y	N	Y	Y	Y	N	N	N
Type	Success	F_{R_0}	F_{R_1}	F_{R_2}	F_0	F_1	F_2	

where "Y" means success and "N" means failure. The notations F_{R_0} , F_{R_1} , F_{R_2} , F_0 , F_1 and F_2 are the transmission types to be defined.

Case 1 and case 2 are considered as successful transmissions since both D_1 and D_2 successfully received information from the source node. In case 3, the transmitted packet is called F_{R_0} -packet and stored in the R_0 . In case 4, the transmitted packet is called F_{R_1} -packet and stored in R_1 . In case 5, the transmitted packet is called F_{R_2} -packet and stored in R_2 . For the above cases, the source node doesn't need an additional transmission. However, case 6-8 are regarded as unsuccessful transmissions since at most one destination node received information from the source. In these cases, the source node needs another transmission for the transmitted packet. The transmitted packet in case 6-8 are called F_0 -, F_1 - and F_2 -packet respectively. Besides, the initial packet to be transmitted is also called F_0 -packet.

When the relay decodes the packet successfully (unsuccessfully), it will send an ACK (NACK) message to the source. So the source knows the success (failure) of the transmission to the relay. When the source node transmits a packet to the destination nodes, the destinations will broadcast ACK or NACK messages to both the source nodes and relay according to the decoding status. Therefore, the source nodes and the relay will know success (failure) of this transmission. Similarly, when the relay transmits packet to the destination

nodes, the destination nodes will also send ACK or NACK messages to the relay. In the following, we introduce the dynamic network coding strategies based on the relay queue sizes, which allow different priorities (in terms of order of transmission) to the three kinds of packets F_{R_0} , F_{R_1} , F_{R_2} .

Strategy 1: When the slot of source node is sensed free, the relay can transmit the packet to the destination. The transmitting strategy in the relay is as follows: the relay node first transmits the F_{R_0} -packet if R_0 is not empty. Otherwise, Only if R_1 is empty, the relay transmits the F_{R_2} -packet to D_1 ; only if R_2 is empty, the relay transmits the F_{R_1} packet to D_2 ; if none of R_1 and R_2 is empty, the relay performs network coding for the packets in R_1 and R_2 and transmits $F_{R_1} \oplus F_{R_2}$ to the destination; if R_1 and R_2 are both empty, the relay keeps idle.

Strategy 2: The transmitting strategy in the relay is as follows: the relay node first transmits $F_{R_1} \oplus F_{R_2}$, if none of R_1 and R_2 is empty; the relay transmits F_{R_1} (F_{R_2}) to D_2 (D_1) if only R_2 (R_1) is empty; the relay transmits F_{R_0} to the destination only if both R_1 and R_2 are empty; the relay keeps idle if R_0 , R_1 and R_2 are all empty.

Strategy 3: Combine the three queues into one queue, and all the three kind packets F_{R_0} , F_{R_1} and F_{R_2} are put into the queue sequentially. At each sensed empty time slot, the packets in the relay are transmitted according to the FIFO (First In First Out) rule.

In our queueing model, the time is slotted, and in each time slot there is no more than one packet to be transmitted (all the packets are assumed to have the same packet length). The packet arrival processes at S_1 and S_2 are both independent and stationary with rate λ_1 and λ_2 (packets per slot) respectively. Both source nodes access the channel according to the TDMA protocol. Let $\Omega = [\omega_1, \omega_2]$ denote a time-sharing vector, where ω_i denotes the probability that time slot is allocated to the source node i .

Stability is an important performance metric in the queueing analysis [15]. In this paper, the stability is defined as in [14], i.e.,

$$\lim_{t \rightarrow \infty} P[Q_i(t) = 0] > 0, \quad (1)$$

where $Q_i(t)$ means the length of the waiting packets in the i th queue at time t . If the arrival and departure rates of a queueing system are stationary, then Loynes theorem can be used to check the stability of the queue. The i th queue of the source node is considered to be stable if the average arrival rate is less than the average service rate. If the average arrival rate is greater than the average service rate, the queue is unstable. We don't consider the case that the average arrival rate is equal to the average service rate as there is a possibility of subtle limiting behavior.

All wireless channels between any two nodes in the system are modeled as independent stationary Rayleigh flat-fading channels with additive Gaussian noise. The channel coefficients h_{ij}^t is modeled as *i.i.d* zero mean, circularly symmetric complex Gaussian random process with unit variance. The node transmits with normalized power $P = 1$. without loss of

generality, the noise at all the receiver is modeled as *i.i.d* zero mean, circularly symmetric complex Gaussian random process with unit variance. We also assume that the channel fading coefficients are known only to the corresponding receivers, but not known to the transmitters.

The instant received SNR of a signal transmitted from node i to node j can be shown to be $\text{SNR}_{ij} = \frac{\gamma_{ij}|h_{ij}|^2 P_i}{N_0}$, where $|h_{ij}|^2$ denotes the magnitude channel gain square which has an exponential distribution with unit mean. γ_{ij} denotes the average channel power gain due to the shadowing and path loss.

The transmission of a given packet is regarded to be successful if the received SNR is above a given threshold β , which can be chosen according to the QoS requirement. Therefore, the probability of outage of the transmission can be shown to be $P_{\text{out},ij} = P[\text{SNR}_{ij} < \beta] = 1 - \exp\left(-\frac{\beta}{\gamma_{ij}}\right)$, which follows from the exponential distribution of the received SNR. So the success probability of the transmission at SNR threshold β is

$$P_{i,j} = \exp\left(-\frac{\beta}{\gamma_{ij}}\right). \quad (2)$$

III. STABILITY ANALYSIS FOR STRATEGY 1

As there are three kinds of packets in the sources S_1 and S_2 , we should study the arrival and service rate of the three kind packets to analyze the stability of the sources' queue.

A. Stability condition for S_1 and S_2

Consider only the F_0 packet in S_1 . Similar in [5] and [14], the queue size (in packets) of S_1 evolves as

$$Q_1(t) = (Q_1(t-1) - Y_{1,0}(t))^+ + X_{1,0}(t),$$

where $X_{1,0}(t)$ is the stationary process representing the number of arrivals of the F_0 packet, $Y_{1,0}(t)$ is the service process of F_0 packet, and $(x)^+ = \max(x, 0)$. For simplicity, we will omit t in the following analysis. We also assume that the queue size is measured at the beginning of the slot. Let A_1 be the time slot allocated to S_1 . From the system model, we know that the probability of $\{A_1 = 1\}$ is ω_1 . Let $O_{S_1 D_1}$ denote the event that S_1 transmits successfully to D_1 , which probability is assumed to be $P_{S_1 D_1}$ and can be determined by (2). Similarly, $O_{S_1 D_2}$ and $O_{S_1 R}$ denote the events that S_1 transmits successfully to D_2 and R respectively, which probabilities are assumed to be $P_{S_1 D_2}$ and $P_{S_1 R}$ respectively, and determined by (2). From the system model, the service process of the F_0 packet in S_1 is $Y_{1,0} = \chi_{A_1 \cap (O_{S_1 D_1} \cup O_{S_1 D_2} \cup O_{S_1 R})}$, where $\chi_{\{\cdot\}}$ is the indicator function. So the service rate of the F_0 -packet in S_1 is

$$\mu_{1,0} = \omega_1(1 - P_{1,3}), \quad (3)$$

where $P_{1,3} = (1 - P_{S_1 D_1})(1 - P_{S_1 D_2})(1 - P_{S_1 R})$.

When S_1 transmits a packet only successfully to D_1 , the packet in S_1 becomes the F_1 -packet. The arrival process of the F_1 -packet in S_1 is $X_{1,1} = \chi_{\{A_1 \cap \{Q_{1,0} \neq 0\} \cap O_{S_1 D_1} \cap \overline{O_{S_1 R}} \cap \overline{O_{S_1 D_2}}\}}$, where $\{Q_{1,0} \neq 0\}$ denotes the event of S_1 transmitting the F_0 packet, which

probability, by Little's theorem, is $\frac{\lambda_1}{\omega_1(1-P_{1,3})}$. So the **arrival rate** of the F_1 packet in S_1 is

$$\lambda_{1,1} = E[X_{1,1}] = \frac{\lambda_1 P_{S_1 D_1}}{1 - P_{1,3}} (1 - P_{S_1 R})(1 - P_{S_1 D_2}). \quad (4)$$

Next, we consider the service process of the F_1 -packet in S_1 . When the F_1 -packet is transmitted successfully to R or D_2 , it can leave the source node. So the service process is $Y_{1,1} = A_1 \cap (O_{S_1 R} \cup O_{S_1 D_2})$. Then the **service rate** for F_1 -packet in S_1 is

$$\mu_{1,1} = \omega_1(P_{S_1 R} + P_{S_1 D_2} - P_{S_1 R} P_{S_1 D_2}). \quad (5)$$

Similarly, when S_1 transmits the packet only successfully to D_2 , the packet becomes the F_2 -packet in S_1 . Then the **arrival rate** of the F_2 packet in S_1 is

$$\lambda_{1,2} = \frac{\lambda_1 P_{S_1 D_2}}{1 - P_{1,3}} (1 - P_{S_1 R})(1 - P_{S_1 D_1}), \quad (6)$$

and the **service rate** of the F_2 -packet in S_1 is

$$\mu_{1,2} = \omega_1(P_{S_1 R} + P_{S_1 D_1} - P_{S_1 R} \cdot P_{S_1 D_1}). \quad (7)$$

From the Loynes' theorem, the stability condition for S_1 is

$$\frac{\lambda_1}{\mu_1} = \frac{\lambda_1}{\mu_{1,0}} + \frac{\lambda_{1,1}}{\mu_{1,1}} + \frac{\lambda_{1,2}}{\mu_{1,2}} < 1, \quad (8)$$

where μ_1 denotes the average service rate of S_1 . Similarly, the stability condition for S_2 is

$$\frac{\lambda_2}{\mu_2} = \frac{\lambda_2}{\mu_{2,0}} + \frac{\lambda_{2,1}}{\mu_{2,1}} + \frac{\lambda_{2,2}}{\mu_{2,2}} < 1, \quad (9)$$

where μ_2 denotes the average service rate of S_2 .

B. Stability condition for relay

The arrival process of the packet in S_1 that transmits successfully only to the relay is:

$$A_1 \cap \{Q_{1,0} \neq 0\} \cap O_{S_1 R} \cap \overline{O_{S_1 D_2}} \cap \overline{O_{S_1 D_1}}. \quad (10)$$

Since the arrival process to the relay is stationary, the expected arrival rate of R_0 from S_1 and S_2 are respectively

$$\lambda_{R,0,1} = \frac{\lambda_1}{1 - P_{1,3}} P_{S_1 R} (1 - P_{S_1 D_1})(1 - P_{S_1 D_2}), \quad (11)$$

$$\lambda_{R,0,2} = \frac{\lambda_2}{1 - P_{2,3}} P_{S_2 R} (1 - P_{S_2 D_1})(1 - P_{S_2 D_2}), \quad (12)$$

where $P_{2,3} = (1 - P_{S_2 D_1})(1 - P_{S_2 D_2})(1 - P_{S_2 R})$. Therefore R_0 has **arrival rate** $\lambda_{R_0} = \lambda_{R,0,1} + \lambda_{R,0,2}$.

The service process of R_0 consists of three parts: i.) R_0 transmits successfully to D_1 and D_2 ; ii.) Packet in R_0 transmits only successfully to D_1 and is moved to R_1 ; iii.) Packet in R_0 transmit only successfully to D_2 and is moved to R_2 . So the event of service process of R_0 is

$$A_1 \cap \{Q_1 = 0\} \cap (O_{RD_1} \cup O_{RD_2}) \\ + A_2 \cap \{Q_2 = 0\} \cap (O_{RD_1} \cup O_{RD_2}).$$

Hence the **service rate** of R_0 is

$$\begin{aligned}\mu_{R_0} &= \left[\omega_1 \left(1 - \frac{\lambda_1}{\mu_1} \right) + \omega_2 \left(1 - \frac{\lambda_2}{\mu_2} \right) \right] \\ &\quad \times (P_{RD_1} + P_{RD_2} - P_{RD_1}P_{RD_2}). \quad (13)\end{aligned}$$

So the stability condition of R_0 is $\lambda_{R_0} < \mu_{R_0}$.

There are three cases for R_1 : i.) Packet in S_1 transmits successfully to both relay and D_1 ; ii.) F_1 packet transmits successfully to the relay; iii.) Packet in R_0 transmits successfully to D_1 and is moved to R_1 .

- i) The arrival process of the packet in S_1 that transmits successfully to the relay and D_1 is: $A_1 \cap \{Q_{1,0} \neq 0\} \cap O_{S_1D_1} \cap O_{S_1R} \cap \overline{O_{S_1D_2}}$. Then the arrival rates

$$\begin{aligned}\lambda_{R,1,1} &= \frac{\lambda_1}{1 - P_{1,3}} P_{S_1R} P_{S_1D_1} (1 - P_{S_1D_2}) \\ &\quad + \frac{\lambda_2}{1 - P_{2,3}} P_{S_2R} P_{S_2D_1} (1 - P_{S_2D_2}), \quad (14)\end{aligned}$$

where $P_{2,3} = (1 - P_{S_2D_1})(1 - P_{S_2D_2})(1 - P_{S_2R})$.

- ii) The arrival process of the F_1 -packet transmits successfully to R and becomes F_{R_1} -packets is $X_{1,1} = A_1 \cap \{Q_{1,1} \neq 0\} \cap O_{S_1R} \cap \overline{O_{S_1D_2}}$, where $\{Q_{1,1} \neq 0\}$ denotes the event of the source node transmitting the F_1 -packet. By using Little's theorem, the probability of $\{Q_{1,1} \neq 0\}$ is $\frac{\lambda_{1,1}}{\mu_{1,1}}$. So the arrival rate of the F_2 -packet of S_1 into R_1 is

$$\frac{\lambda_1}{1 - P_{1,3}} \cdot \frac{P_{S_1D_1}(1 - P_{S_1R})(1 - P_{S_1D_2})}{P_{S_1R} + P_{S_1D_2} - P_{S_1R}P_{S_1D_2}}. \quad (15)$$

Hence the arrival rate of the F_1 -packet from S_1 and S_2 into R_1 can be calculated as

$$\begin{aligned}\lambda_{R,1,2} &= \frac{\lambda_1}{1 - P_{1,3}} P_{S_1D_1} (1 - P_{S_1R})(1 - P_{S_1D_2}) \\ &\quad \times \frac{P_{S_1R}(1 - P_{S_1D_2})}{P_{S_1R} + P_{S_1D_2} - P_{S_1R}P_{S_1D_2}} \\ &\quad + \frac{\lambda_2}{1 - P_{2,3}} P_{S_2D_1} (1 - P_{S_2R})(1 - P_{S_2D_2}) \\ &\quad \times \frac{P_{S_2R}(1 - P_{S_2D_2})}{P_{S_2R} + P_{S_2D_2} - P_{S_2R}P_{S_2D_2}}. \quad (16)\end{aligned}$$

- iii) The arrival process for the packet in R_0 that transmits successfully to D_1 and is moved to R_1 , is $A_1 \cap \{Q_1 = 0\} \cap \{Q_{R_0} \neq 0\} \cap O_{RD_1} \cap \overline{O_{RD_2}}$, where $\{Q_{R_0} \neq 0\}$ denotes the event that the R_0 is not empty, which probability, by using Little's theorem, is $\frac{\lambda_{R_0}}{\mu_{R_0}}$. So the arrival rate is

$$\begin{aligned}\lambda_{R,1,3} &= \omega_1 \left(1 - \frac{\lambda_1}{\mu_1} \right) \frac{\lambda_{R_0}}{\mu_{R_0}} P_{RD_1} (1 - P_{RD_2}) \\ &\quad + \omega_2 \left(1 - \frac{\lambda_2}{\mu_2} \right) \frac{\lambda_{R_0}}{\mu_{R_0}} P_{RD_1} (1 - P_{RD_2}), \quad (17)\end{aligned}$$

By (13), we have

$$\lambda_{R,1,3} = \lambda_{R_0} (P_{RD_1} + P_{RD_2} - P_{RD_1}P_{RD_2}) P_{RD_2} (1 - P_{RD_1}) \quad (18)$$

Combining the three cases, R_1 has **arrival rate**

$$\lambda_{R_1} = \lambda_{R,1,1} + \lambda_{R,1,2} + \lambda_{R,1,3}.$$

By Strategy 1, only when the time slot is assigned to S_1 (S_2), and S_1 (S_2) and R_0 are empty, R_1 has chance to transmit. If R_2 has packet, R_1 and R_2 can do network coding; while if R_2 is empty, R_1 will transmit by itself. For the aforementioned two cases, R_1 will have the same service process and the same service rate. Specifically, the service process of R_1 is

$$\begin{aligned}A_1 \cap \{Q_1 = 0\} \cap \{Q_{R_0} = 0\} \cap O_{RD_2} \\ + A_2 \cap \{Q_2 = 0\} \cap \{Q_{R_0} = 0\} \cap O_{RD_2}. \quad (19)\end{aligned}$$

So the **service rate** of R_1 is

$$\mu_{R_1} = \left[\omega_1 \left(1 - \frac{\lambda_1}{\mu_1} \right) + \omega_2 \left(1 - \frac{\lambda_2}{\mu_2} \right) \right] \left(1 - \frac{\lambda_{R_0}}{\mu_{R_0}} \right) P_{RD_2}. \quad (20)$$

Hence the stability condition of R_1 is $\lambda_{R_1} < \mu_{R_1}$.

Similar as R_1 , R_2 has **arrival rate**

$$\lambda_{R,2} = \lambda_{R,2,1} + \lambda_{R,2,2} + \lambda_{R,2,3},$$

The service rate of R_2 is

$$\mu_{R_2} = \left[\omega_1 \left(1 - \frac{\lambda_1}{\mu_1} \right) + \omega_2 \left(1 - \frac{\lambda_2}{\mu_2} \right) \right] \left(1 - \frac{\lambda_{R_0}}{\mu_{R_0}} \right) P_{RD_1}.$$

Therefore the stability condition of R_2 is $\lambda_{R_2} < \mu_{R_2}$. In summary, we conclude that the stability conditions for strategy 1 are

$$\begin{cases} \frac{\lambda_1}{\mu_{1,1}} + \frac{\lambda_{1,2}}{\mu_{1,2}} + \frac{\lambda_{1,3}}{\mu_{1,3}} < 1, \\ \frac{\lambda_2}{\mu_{2,1}} + \frac{\lambda_{2,2}}{\mu_{2,2}} + \frac{\lambda_{2,3}}{\mu_{2,3}} < 1, \\ \lambda_{R_0} < \mu_{R_0}, \\ \lambda_{R_1} < \mu_{R_1}, \\ \lambda_{R_2} < \mu_{R_2}. \end{cases} \quad (21)$$

IV. STABILITY ANALYSIS FOR STRATEGY 2 AND 3

In this strategy, the Similarly, the stability condition for strategy 2 is

$$\begin{cases} \frac{\lambda_1}{\mu_{1,1}} + \frac{\lambda_{1,2}}{\mu_{1,2}} + \frac{\lambda_{1,3}}{\mu_{1,3}} < 1, \\ \frac{\lambda_2}{\mu_{2,1}} + \frac{\lambda_{2,2}}{\mu_{2,2}} + \frac{\lambda_{2,3}}{\mu_{2,3}} < 1, \\ \lambda'_{R_0} < \mu'_{R_0}, \\ \lambda'_{R_1} < \mu'_{R_1}, \\ \lambda'_{R_2} < \mu'_{R_2}. \end{cases} \quad (22)$$

The stability condition of strategy 3 is

$$\frac{\lambda''_{R_0}}{\mu''_{R_0}} + \frac{\lambda''_{R_1}}{\mu''_{R_1}} + \frac{\lambda''_{R_2}}{\mu''_{R_2}} < 1. \quad (23)$$

Moreover, we have the following interesting result for the three strategies.

Theorem 1: The stability region of strategy 1 is bigger than that of strategy 2, and the stability region of strategy 2 is bigger than that of strategy 3.

Proof: Omitted due to limited space.

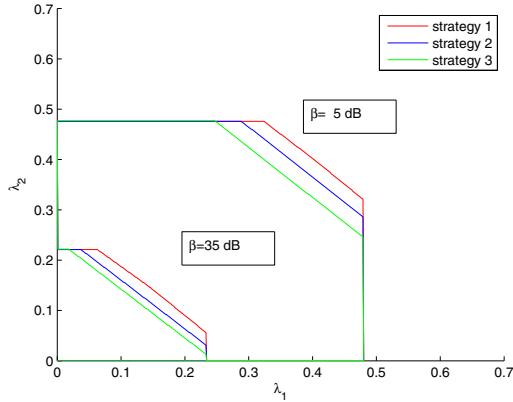


Fig. 2. Stability region under $\beta = 5$ and $\beta = 35$ dB. ($\omega_1 = \omega_2 = 1/2$)

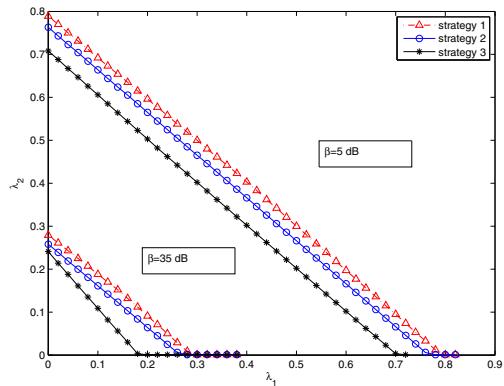


Fig. 3. Maximum stable throughput under $\beta = 5$ dB and $\beta = 35$ dB.

V. NUMERICAL RESULTS

In our Monte-Carlo simulations, parameters are symmetrically selected as $\gamma_{S1R} = \gamma_{S2R} = 40$ dB, $\gamma_{S1D1} = \gamma_{S2D2} = 20$ dB, $\gamma_{S1D2} = \gamma_{S2D1} = 25$ dB, and $\gamma_{RD1} = \gamma_{RD2} = 50$ dB.

Fig. 2 shows the stability regions of the three strategies for $\omega_1 = \omega_2 = 1/2$. We can observe that the strategy 1 and 2 with network coding have larger stability region, and the stability region for strategy 1 is the largest, which validate the theoretical prediction. We can also observe that the stability region for the three strategies become smaller as the required SNR threshold β increases.

Fig. 3 shows the maximum stability regions of the three strategies. We can observe that the maximum stability regions are larger than the corresponding stability regions for $\omega_1 = \omega_2$. Specifically, Regions in Fig. 3 enlarges the corresponding regions in Fig 2 in the areas where either of λ_1 or λ_2 is small.

VI. CONCLUSION

In this paper, we propose an opportunistic relay with regenerative network coding for the multicast cell. Specifically, we propose three relaying transmission strategies with and without network coding. By analyzing the stability region for the three

strategies, we demonstrate that the strategies with opportunistic network coding enjoy large stability regions. In addition, the strategy with opportunistic network coding outperforms that with relative static network coding. By simulation, we also find that the stability regions for the three strategies become smaller as the required received SNR threshold increases.

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