Optimization Frameworks for Wireless Network Coding Under Multi-hop Node Interference

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Abstract— **Based on an information model that classifies intermediate nodes in multicast networks into network coding, routing and replicating nodes, multicast max-flow and minimum cost optimization frameworks are formulated to solve optimization problems of wireless networks with or without network coding. We take two special properties of wireless transmissions into consideration, i.e., cooperation and mutual interference among nodes in multi-hop wireless networks. Using maximal ratio combining (MRC) for node cooperation and using successive interference cancellation (SIC) for interference mitigation, signal-to-interference-plus-noise-ratio (SINR) expressions for each wireless node can be derived. Such expressions are then used to modify the edge capacity in the optimization frameworks. A unique advantage of our approach is that the optimization frameworks are still linear or convex. Analysis and simulations show that the proposed method is promising to capture the cooperation interference nature of wireless communication networks.**

Keywords- network optimization; wireless network; mutual interference; network coding; multicast network

I. INTRODUCTION

The basic idea of network coding is that message sent on a node's output link can be some function of messages that arrived earlier on the node's input links. An important such function is the *XOR* function, which is the addition operation (linear) in finite field $GF(2^n)$. The capacity of multicast networks with network coding was given in [1] as $min_{t\in T} Mincut(s,t)$, which is the upper bound rate of multicast. It has also been verified that linear network coding is sufficient to achieve the multicast capacity [2][3] and the coding coefficients necessary to achieve the capacity can be computed in polynomial time [4][5].

When using network coding, there are two types of minimum cost optimization problems for multicast: i) Find the optimal subgraph to code over, and ii) determine the code to use over the subgraph [6]. In this paper, we focus on the first type of the problems. In [6][7][8], minimum energy cost problem in wireless network was discussed, and a decentralized algorithm was proposed with which the intermediated nodes can decide the code coefficients according to the local information. In practice, since some nodes may not be powerful enough for network coding, especially in wireless networks where nodes are limited by battery power, computing power as well as communication capability, a more reasonable model should take node differentiation into consideration. An interesting node differentiation scheme was considered in [9], where nodes were classified into three different types: routing, replicating and network coding.

There has been much work to extend the network coding from wired networks to wireless networks. An important difference is that the latter have node cooperation and interference due to the broadcasting nature of wireless transmissions. In [10], a finite-field model for the wireless broadcast and additive interference network was considered. It showed that channel fading can contribute to the unicast capacity greatly by using network coding. Dynamic back pressure algorithms were used in [11] to compare multicast network coding and routing for a time-varying interference wireless network. Analog network coding using interfering signals was discussed in [12].

In this paper, we take the cooperation and interference property of wireless transmissions into account to formulate multicast max-flow optimization and minimum energy cost optimization frameworks in wireless networks with or without network coding. Assuming that the nodes apply maximum ratio combining (MRC) to collect all broadcast signals and use successive interference cancellation (SIC) to mitigate broadcasting interference, we will derive the signal-to-interference-plus-noise-ratio (SINR) expressions for wireless nodes and use them to modify the edge capacities of the optimization frameworks. The objective is to keep the optimization framework linear or convex for global convergence.

For convenience, Table 1 lists some important notations used in this paper.

II. INFORMATION MODEL WITH NODE DIFFERENTIATION

Consider network (V, E), where V is the set of nodes (vertices), E is the set of edges (directed links). In this paper, we consider the single source multicast problem over a network, while the multiple independent source multicast problems can be converted to single source problem as shown in [1]. Multicast session (s,T) stands for a multicast session which has a sender $\mathrm{s}\in\mathrm{V}$ and a set of receivers $\mathrm{T}\subseteq\mathrm{V}$. To model all the possible receiver sets in the multicast problem, we define sets P and Q .Let c_i be the non-negative broadcast capacity for node *i*, X_{ij} be a 2^K-1 dimentional information flow vector which is also the optimization variable, where its l-th element $x_{ij}(P_l)$ represents the amount of information common to and only common to the receivers in the set P_l. Details can be found in [13].

TABLE I
NOTATIONS USED IN THE PAPER

(V, E)	a network, V is the set of nodes, E is the set of edges (directed links)
c_i	non-negative broadcast capacity of node *i*, c_{ij} is the capacity of edge (*i*,*j*).
a_i	non-negative cost per unit flow transmitted by node *i*
d_{ij}	the distance between nodes *i* and *j*
(s, T)	a single source multicast session which has a sender $s \in V$ and a set of receivers $T \subseteq V$
K	the number of receivers in T
P	the power set of T (except the empty set), P_l is its l-th element if fixing the ordering
Q	a set containing all collections of two or more disjoint sets in *P*, Q_m is its m-th element if fixing the ordering
X_{ij}	a $2^K - 1$ dimensional information flow vector associated with the edge (i, j), $x_{ij}(P_l)$ is its l-th element which represents the amount of information common to and only common to the receivers in the set P_l
R	the transmission rate
r_m^i	a routing/replication variable associated with set Q_m at node *i*, which is the flow meant for each receiver in the set $\cup_{Q \in Q_m} Q$ being replicated with each copy meant for a set in Q_m
n_m^i	a network coding variable associated with set Q_m at node *i*, which is the amount of flow meant for each set of receivers $Q \in Q_m$ that merges to form one flow that reach all receivers in the set $\cup_{Q \in Q_m} Q$
z_{ij}	the actual information flow on each edge $(i, j) \in E$
P	the transmission power

A. *"Edge" constraints*

The wireless network can be treated as a special wire-line network with broadcasting, so we can still use the "edge" concept for simplification. Here, the "edge" constraints means that the amount of information common to all sets $P_l \in P$ that are transmitted by the node *i* can not beyond the broadcast capacity of the node *i*. We can describe it as

$$\sum_j \sum_{P_l \in P} x_{ij}(P_l) \le c_i, \forall i \in N \qquad (1)$$

B. *Node constraints*

For the sender s, the in-link flow is 0, while the out-link flow is R. For the receiver t, the in-link flow is R, while the out-link flow is 0. For any intermediate node, the in-link flow must be equal to the out-link flow. R is the transmission rate. In the max-flow problem, R is the objective function for maximization. On the other hand, in the minimum cost problem, R serves as a constraint—the transmission rate we want to meet at minimum cost.

For the sender s, node constraint is

$$\sum_{l: t \in P_l} \sum_{(s,j) \in E} x_{sj}(P_l) = R_1, \forall t \in T \qquad (2)$$

which means that all information common to the receiver t passing through all out-links of the sender s is R_1 which is the rate of the information flow that we want to support. Obviously R_1 is no more than the max flow R.

For the receiver t, node constraint is

$$\sum_{l: t \in P_l} \sum_{(j,t) \in E} x_{jt}(P_l) = R_1, \forall t \in T \qquad (3)$$

which means all information common to the receiver t passing through all in-links of the receiver t is R_1.

The node constraints for intermediate nodes are quite complex when considering node differentiation. There are three types of nodes, as shown in Figure 1. For routing nodes, nothing happens to the information flow. For replicating nodes, it replicates the packets and each copy of the packet on the out-link needs to reach nodes in a set $P_l \in Q_m$. For network coding nodes, two or more flows merge. Note that a node can be routing/ replicating/network coding node at the same time. Figure 1 lists the node constraints for these three types of intermediate nodes.

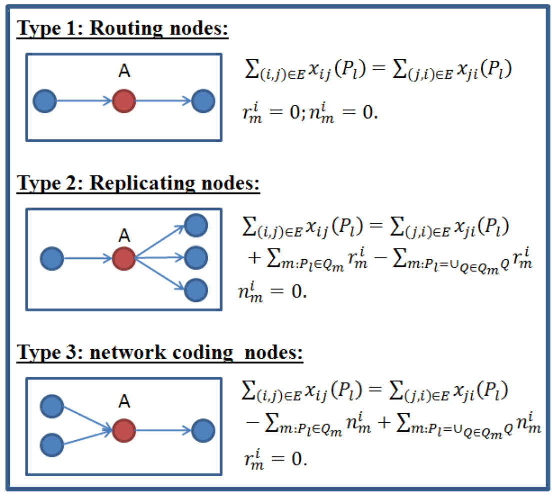


Figure 1. Illustration of the three types intermediate nodes and associated node constraint.

Combining these node constraints, for each intermediate node, a general node constraint is

$$\sum_{(i,j) \in E} x_{ij}(P_l) = \sum_{(j,i) \in E} x_{ji}(P_l) + \sum_{m: P_l \in Q_m} (r_m^i - n_m^i) - \sum_{m: P_l = \cup_{Q \in Q_m} Q} (r_m^i - n_m^i), \forall P_l \in P \qquad (4)$$

III. OPTIMIZATION FRAMEWORK FOR NETWORK CODING

A. *Multicast Maxflow problem*

The major advantage of network coding is that the upper bound of multicast capacity can be achieved. In other words, the value of maximum flow depends heavily on whether we allow the network to perform network coding. Given the "edge" and node constraints, we can formulate the optimization framework of the multicast max flow problem as follows.

$$
\begin{aligned}
&\textit{maximum} \quad R \\
&\text{subject to} \\
&x_{ij}(P_l) \ge 0, \forall P_l \in P, \forall (i,j) \in E \\
&r_m^i \ge 0, n_m^i \ge 0, \forall m, \forall i \in V \\
&\underline{\text{Edge Constraints:}} \\
&\textstyle\sum_j \sum_{P_l \in P} x_{ij}(P_l) \le c_i, \forall i \in N \\
&\underline{\text{Node Constraints:}} \\
&\textstyle\sum_{l: t \in P_l} \sum_{(s,j) \in E} x_{sj}(P_l) = R, \forall t \in T \\
&\textstyle\sum_{l: t \in P_l} \sum_{(j,t) \in E} x_{jt}(P_l) = R, \forall t \in T \\
&\textstyle\sum_{(i,j) \in E} x_{ij}(P_l) = \sum_{(j,i) \in E} x_{ji}(P_l) + \sum_{m: P_l \in Q_m} (r_m^i - n_m^i) \\
&\qquad\qquad - \textstyle\sum_{m: P_l = \cup_{Q \in Q_m} Q} (r_m^i - n_m^i), \\
&\qquad\qquad \forall P_l \in P, \forall i \in V - \{s, T\}
\end{aligned}
$$

B. Minimum energy optimization in wireless networks

Wireless networks are a special type of networks that has "multicast advantage", which means that if signal is transmitted from node *i* to node *j*, then all nodes whose distance from *i* is smaller than *j* can receive this signal for free. This is due to the broadcasting nature of wireless transmission, and the transmitted signal strength attenuates rapidly along with transmission distance. This broadcasting property of wireless transmissions makes the set of out-links from a node *i* is a set that include all the wireless nodes within a certain fixed radius of the node *i*. As shown in [7], the network optimization model in previous sections can be conveniently modified to take the broadcasting nature of wireless transmission into consideration.

1) Constraint assocatied with broadcast property

Define a new variable z_i which is corresponding to the actual broadcast information flow from node *i*. With network coding, it is limited by the maximum flow rate to any receiver from the node *i*,

$$c_i \geq z_i \geq \sum_j \sum_{l:t\in P_l} x_{ij}(P_l), \forall t \in T, \forall i, j \in V. \quad (5)$$

Without network coding, it is the sum of the information flow transmitted by the node *I*,

$$c_i \geq z_i = \sum_j \sum_{P_l \in P} x_{ji}(P_l), \forall i \in V - \{s, T\}, \forall j \in V;$$
$$c_i \geq z_s = R_1; z_t = 0, \forall t \in T. \quad (6)$$

Obviously, z_i is no more than the broadcasting capacity c_i. More explanation can be found in [13].

2) Energy cost objective function

Based on the information model in Section II, many natural cost criteria can be used in minimum cost optimization problem, such as the number of network coding node (i.e., $\sum_i n(i)$, where $n(i) = 1$ if $n_m^i > 0$ for some m and $n(i) = 0$, otherwise), or the number of network coding operations i.e., (i.e., $\sum_i n_m^i$)[9]. Considering that wireless nodes are usually primarily limited in energy supply, we choose the energy usage as the cost for optimization.

Assumption 1: *All nodes in the network have the same transmission power P.*

The transmission energy cost is proportional to the actual information flow transmitted by the node *i*,

$$Energy\ cost = P\frac{Z_i}{c_i} \times unit\ time = a_i z_i \quad (7)$$

where a_i is the non-negative cost per unit flow transmitted by the node *i*.

For the minimum energy cost problem, the optimization objective function is the sum of z_i weighted by a_i. As a result, the summation is the cost to transmit data to all receivers at rate R_1.

Now, we can formulate the framework of minimum energy optimization problem in multicast wireless networks as follows.

$minimize \quad \sum_i a_i z_i, \forall i \in V$
$subject\ to$
$x_{ij}(P_l) \geq 0, \forall P_l \in P, \forall i, j \in V$
$r_m^i \geq 0, n_m^i \geq 0, \forall m, \forall i \in V$

<u>Broadcast Constraints:</u>

For node i with $n_m^i > 0$ for some m
$c_i \geq z_i \geq \sum_j \sum_{l:t\in P_l} x_{ij}(P_l), \forall t \in T, \forall i, j \in V$
For node i with $n_m^i = 0$ for all m
$c_i \geq z_i = \sum_j \sum_{P_l \in P} x_{ji}(P_l), \forall i \in V - \{s, T\}, \forall j \in V$
$c_i \geq z_s = R_1, z_t = 0, \forall t \in T;$

<u>Edge Constraints:</u>

$\sum_j \sum_{P_l \in P} x_{ij}(P_l) \leq c_i, \forall i, j \in N$

<u>Node Constraints:</u>

$\sum_{l:t\in P_l} \sum_j x_{sj}(P_l) = R_1, \forall t \in T, \forall j \in V$
$\sum_{l:t\in P_l} \sum_j x_{jt}(P_l) = R_1, \forall P_l \in P, \forall t \in T, \forall j \in V$
$\sum_j x_{ij}(P_l) = \sum_j x_{ji}(P_l) + \sum_{m:P_l \in Q_m}(r_m^i - n_m^i) - \sum_{m:P_l = \cup_{Q \in Q_m} Q}(r_m^i - n_m^i),$
$\forall P_l \in P, \forall i, j \in V - \{s, T\}$

For applying this framework, we can easily add other constraints as well, such as those associated with the node types, e.g., specifying that the node *i* is not a network coding node by $n_m^i = 0, \forall m$, or specifying that the node *i* is a routing node by $r_m^i = 0, n_m^i = 0, \forall m$. We may also add constraints with respect to other special wireless transmission properties besides the broadcasting nature addressed in this paper.

For wireless networks, however, one of the big issues is the determination of the parameters c_i or a_i. Considering that the capacity of wireless networks is still an open problem, with only some limited research results in literature, we have to adopt some reasonable assumptions and approximations for simplicity.

Assumption 2: *If a node i transmits with a power P, then the received signal power by a node j is Pg_{ij}, where $g_{ij} = Md_{ij}^{-\alpha}$ with the path loss exponent α, transmission distance d_{ij}, and constant M decided by the antenna parameters and signal carrier frequency.*

Note that we do not consider other small scale fading in this paper. Obviously, we need to limit the minimum distance among the nodes to be no less than 1 to avoid the impractical results that the receiving power becomes higher than the transmission power.

Based on this assumption, if we assume the wireless network is interference free, then c_i and a_i only depend on the transmission distance. This case is almost trivial. However, when considering the mutual interference among the nodes, the broadcast capacity becomes quite complex. We deal with this case in section IV.

IV. NODE COOPERATION AND MUTUAL INTERFERENCE

First, let us use the following assumption.

Assumption 3 (Simultaneous transmission and receiving assumption): Every node can receive a new signal while transmitting its own signal.

This assumption can greatly simplify our SINR and capacity analysis, because otherwise we have to consider endlessly many different transmission scheduling schemes. In [14], we explained that the simultaneous transmission and receiving assumption may not cause theoretical problems. Note that although we assume that a node can conduct transmission and receiving simultaneously, it cannot transmit and receive/decode the same packet simultaneously. Instead, a data packet can be transmitted only after it has been decoded during previous slots.

Consider an *H*-hop transmission path that transmits a specific data stream via *H* hops. Only *H* nodes in the transmission path have cooperation and mutual interference associated with the data stream. We denote the $H+1$ nodes as node $0,1,\cdots,H$ according to their order in the transmission path. Referring to [14][15], the received signal of a node *j* in the time slot *k* can be written as

$$x_j(k)=\sum_{i=0}^{H-1}\sqrt{Pg_{ij}}\,e^{j\theta_{i,j}}u(k-i)+\sqrt{N}v_j(k) \quad (8)$$

where $u(k)$ denotes the signal of the packet *k* of the specific data stream, $\theta_{i,j}$ denotes the channel phase of the propagation path from node *i* to node *j*, and $v_j(k)$ denotes the noise received by the node *j* in the time slot *k*. We let all the nodes have the same receiving noise power *N* for simplicity, which means $E\left[\left|v_j(k)\right|^2\right]=1$. We also let the packet signal $u(k)$ have unit norm $E[|u(k)|^2]=1$.

Assumption 4: We employ decode and forward strategy.

Based on the assumption 4 and using successive interference cancellation (SIC), with the knowledge of all channels, the node *j* can remove the known packets from (8) and reduce $x_j(k)$ to

$$\hat{x}_j(k)=\sum_{i=0}^{j-1}\sqrt{Pg_{ij}}\,e^{j\theta_{i,j}}u(k-i)+\sqrt{N}v_j(k) \quad (9)$$

Note that interesting property from (9), i.e., any node *i* after the node *j* in the transmission path does not play a role in the SINR of the node *j*, as well as node *i* itself. This is because the signal transmitted by the node *i* after the node *j* is known to the node *j*.

According to (9), the node *j* can obtain *j* received signals from time slots $k-j+1,\cdots,k-1,k$ that contains information about the same data packet $u(k-j+1)$. The general form is

$$\hat{x}_j(k-l)=\sum_{i=0}^{j-l-1}\sqrt{Pg_{ij}}\,e^{j\theta_{i,j}}u(k-l-i)+\sqrt{N}v_j(k-l) \quad (10)$$

where $l=j-1,\cdots,0$. The SINR for the signal $\hat{x}_j(k-l)$ is

$$s_j(k-l)=\frac{Pg_{j-l-1,j}}{\sum_{i=0}^{j-l-2}Pg_{i,j}+N} \quad (11)$$

We can use all these *j* received signals to detect the packet $\mathrm{u}(\mathrm{k}-\mathrm{j}+1)$, which needs to be optimally combined to maximize the SINR. One of the ways for optimal combining is the maximal ratio combining (MRC). The SINR for the node *j* when using MRC is thus [14]

$$s_j=\sum_{l=0}^{j-1}s_j(k-l)=\sum_{l=0}^{j-1}\frac{Pg_{j-l-1,j}}{\sum_{i=0}^{j-l-2}Pg_{i,j}+N}. \quad (12)$$

The SINR expression (12) takes all the node cooperation and interference into consideration. Nevertheless, we can conduct some simplification by the following assumption.

Assumption 5: For the SINR of the node j, there exists a node i which has a dominating contribution.

Note that this assumption is specific to the multi-hop node optimization [13]. Usually, the dominating node is the one that is the closest in distance to the node *j*, or the immediate pre-hop. In this case, this assumption is reasonable because otherwise, if the combination transmission of the previous hops is even stronger than the hop from the node *i* to the node *j*, then the node *i* in fact wastes its transmission power.

According to the assumption 5, we consider the case that the first term in s_j $(l=0)$ is dominating, which means

$$\frac{Pg_{j-1,j}}{\sum_{i=0}^{j-2}Pg_{i,j}+N}\gg\sum_{l=1}^{j-1}\frac{Pg_{j-l-1,j}}{\sum_{i=0}^{j-l-2}Pg_{i,j}+N} \quad (13)$$

Then, we can reduce the SINR expression (12) to

$$\hat{s}_j=\frac{Pg_{j-1,j}}{\sum_{i=0}^{j-2}Pg_{i,j}+N} \quad (14)$$

as the approximate SINR at the node *j* for detecting the packet $\mathrm{u}(\mathrm{k}-\mathrm{j}+1)$.

An interesting explanation of (14) is that, for a specific time slot, only the dominating node *i* transmits signal to the node *j*. All other nodes' signals are looked as interference by the node *j*. If there are *N* transmission paths, for the node *j*, there might be *N* dominating nodes i_l (*l*=1…*N*) which transmit different data streams. We assume the node *j* can separate these signals and receive/decode these signals at the same time slot successfully. In other words, we don't treat these signals as interference to each other.

According to SINR (14), the capacity of the node *j-1* is

$$c_{j-1}=log_2\left(1+\hat{s}_j\right)=log_2\left(1+\frac{Pg_{j-1,j}}{\sum_{i=0}^{j-2}Pg_{i,j}+N}\right) \quad (15)$$

Similarly, the capacity for the node *i* is

$$c_i=log_2\left(1+\frac{Pg_{i,j}}{\sum_{k=0}^{i-1}Pg_{k,j}+N}\right) \quad (16)$$

Using (16) as the broadcast capacity of the node *i* in the minimum energy optimization framework in Section III, we then have the optimization frameworks for interference wireless networks with or without network coding.

V. SIMULATION

In this section, we simulate the minimum energy cost optimization of a simple multi-source multi-sink interference wireless network which is shown in Figure 2. Because all the sources are multicast to the same set of nodes in this network, this optimization problem can be reduced to a single-source network coding problem [1] which will be the classical butterfly network problem. There are two senders S_1 , S_2 which can transmit data streams at different multicast rates; two intermediated nodes R_1,R_2 and a receiver set $\{D_1,D_2\}$. The broadcast circle of each node is shown in dashed line in Figure 2. We assume all nodes inside a broadcast circle can receive the signal sent by the center node successfully.

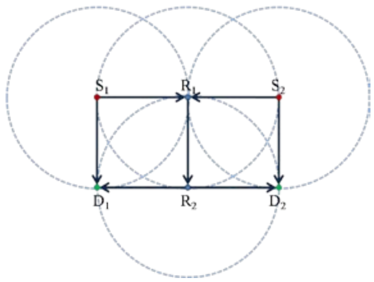


Figure 2. Illustration of a multi-source multi-sink wireless network.

Based on the assumption 3, the multiple multicasts follow the slotted transmission schedule shown in Figure 3. The node R_1 can combine the information flows via network coding. Moreover, some nodes transmit signals at the same time slot, which means mutual interference to the receivers, such as that the node R_2 receives $a_1 \oplus b_1$ as signal and a_2, b_2 as interference at time slot 2.

Slot#	1	2	3	…	k
Node S_1	Tx a_1	Tx a_2	Tx a_3	…	Tx a_k
Node S_2	Tx b_1	Tx b_2	Tx b_3	…	Tx b_k
Node R_1	Rx a_1 Rx b_1	Tx $a_1 \oplus b_1$ Rx a_2 Rx b_2	Tx $a_2 \oplus b_2$ Rx a_3 Rx b_3	… … …	Tx $a_{k-1} \oplus b_{k-1}$ Rx a_k Rx b_k
Node R_2		Rx $a_1 \oplus b_1$	Tx $a_1 \oplus b_1$ Rx $a_2 \oplus b_2$	… …	Tx $a_{k-2} \oplus b_{k-2}$ Tx $a_{k-1} \oplus b_{k-1}$
Node D_1	Rx a_1	Rx a_2	Rx a_3 Rx $a_1 \oplus b_1$	… …	Rx a_k Rx $a_{k-2} \oplus b_{k-2}$
Node D_2	Rx b_1	Rx b_2	Rx b_3 Rx $a_1 \oplus b_1$	… …	Rx b_k Rx $a_{k-2} \oplus b_{k-2}$

Figure 3. Transmission and receiving slots.

Based on the assumption 5 and the SINR (14), Figure 4 illustrates all the mutual interference of the multiple multicasts. At time slot k, the node R_2 receives $a_{k-1} \oplus b_{k-1}$ as signal (red line) and a_k, b_k as interference(red dashed line); node D_1 receives $a_{k-2} \oplus b_{k-2}$ as signal (green line) and $a_{k-1} \oplus b_{k-1}$ as interference(green dashed line); node D_2 receives $a_{k-2} \oplus b_{k-2}$ as signal (purple line) and $a_{k-1} \oplus b_{k-1}$ as interference (purple dashed line).

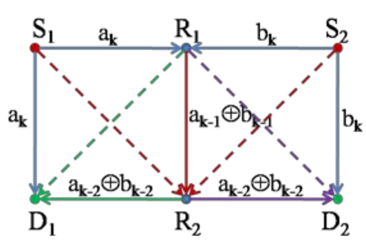


Figure 4. Illustration of interference of transmission.

In our simulations, we also considered nodes movement. Due to the importance of the node R_1, we make it movable as shown in Figure 5. We do not want to change the topology of the network which will unnecessarily make the simulation complex. So in Figure 5 (a), d changes within range [0,0.4]; while in Figure 5 (b), d changes within range [0,0.9].

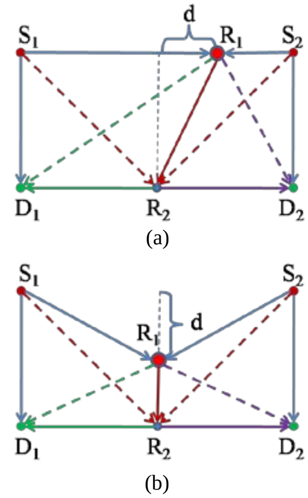


Figure 5. Illustration of node R_1's movement.

In our simulation, we compared three scenarios: 1) using network coding and assuming interference free; 2) using network coding under mutual interference; 3) without network coding and assuming interference free. The

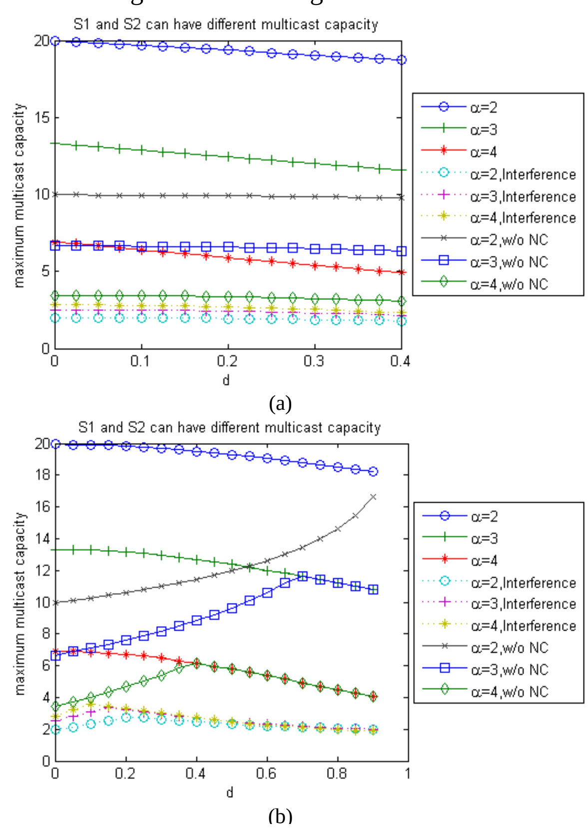


Figure 6. Maximum multicast capacity associated with node R_1's movement.

analysis of mutual interference for the case without network coding is too complex for us to compare here. In other words, network coding can reduce the complexity of network optimization and analysis.

Referring to the multicast max-flow framework in Section III.A, we compared the maximum multicast capacities of these three scenarios in Figure 6. The maximum multicast capacity is the maximum value of the sum of multicast capacity of S_1 and S_2.

Referring to the minimum energy cost optimization framework in Section III.B, we compared the normalized energy cost which is the ratio of the total energy cost and the maximum multicast capacity. The comparison is shown in Figure 7. We assumed S_1 and S_2 have different multicast capacities.

Figure 6(a) and Figure 7(a) are associated with R_1's movement in Figure 5 (a). Figure 6 (b) and Figure 7(b) are associated with R_1's movement in Figure 5 (b). Figure (6) shows:

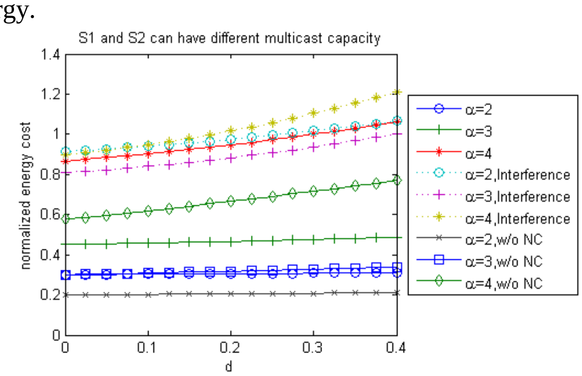
1) Network coding can improve multicast capacity greatly (i.e., from 10 to 20);

2) Considering interference, the multicast capacity becomes quite small (i.e., from 20 for interference-free to 2);

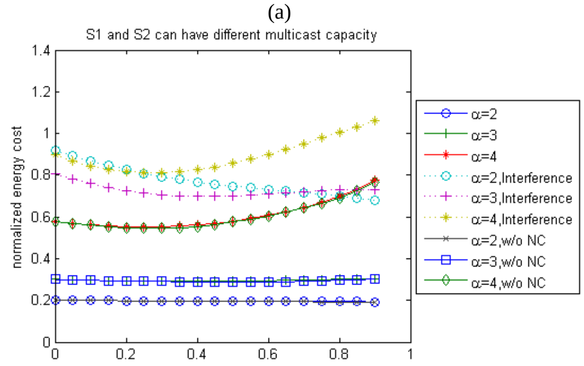
3) Multicast capacity increase with pass loss exponent α for interference free scenario, while decrease for interference scenario;

4) Figure 6 (b) shows that the gap in multicast capacity between network coding and routing can decrease even to 0 due to the collision in the network. Similar conclusion was given in [11].

In Figure 7, the compare results show that energy efficiency decrease distinctly when considering interference or when path loss exponent α becoming larger. Though it seemed that the normalized energy cost is smaller without network coding, this is due to the method we define the energy cost in assumption 1 and the method we define the broadcast capacity. In fact, using network coding we can save energy.



(a)



(b)

Figure 7. Normalized energy cost associated with node R_1's movement.

VI. CONCLUSIONS

In this paper, we take the cooperation and interference property of wireless transmissions into the formulation of the multicast max-flow framework and the minimum energy cost optimization framework of interference wireless networks with or without network coding. Via some reasonable assumptions, we can keep the linear or convex optimization frameworks for global convergence. The simulation results show that network coding has some advantages such as reducing the complexity of network optimization and interference analysis, improving multicast capacity, making the transmission more energy efficiency.

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