Active Mechanism Network Coding Algorithm based on Multi-channel Sensing

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Abstract—In view of the low efficiency and poor coding performance, an active mechanism network coding algorithm based on multi-channel sensing is proposed. The algorithm first establishes a system model to analyze the work pattern of network coding, then selects the minimum sample as cost function and adopts the multi-channel sensing to examine the coding effect of relay node, which makes the network to learn from the coding effect of relay node so as to send the source information to the relay node with better encoding effect. In order to reduce encoding error rate, active mechanism is adopted to improve the capability of network decoding, where the mechanism uses the transmit power of source node and the size of source information to control terminal decoding error rate. The experiment and simulation results show that our proposed network coding algorithm has a very good effect on encoding and decoding processes and can effectively reduce the network overhead.

Index Terms—Network Coding; Multi-Channel Sensing; Active Mechanism; Network Overhead; Relay Node; Encoding Error Rate

I. INTRODUCTION

Network coding is an integration of the decoding technology and the route information exchange technology, which is first proposed by R Ahlswede et al. in the 2000 [1]. In addition, network coding is also a new communication technology, which can promote the throughput significantly and strengthen the reliability of the network service. Network coding mainly uses the intermediate node in network to perform coding and signal processing for channel signal, and then the processed decoding information is sent to the next node, which can attain the maximum possible information flow in a network. Network coding can not only promote the throughput of the network, but also balance the network load and reduce energy consumption which meets the system delay requirements. Compared with the traditional data encryption [2], our improved scheme has a higher safety and reliability. Network coding has become a research focus gradually since it promotes the transmission performance of wireless network efficiently.

Some scholars at home have achieved some research results. Qu Yuben et al. [3] propose a network coding algorithm based on the Markov state transfer. According to some researches on random linear network coding, the Markov state transfer method is adopted to analyze the delay expectation and probability distribution of the unicast flow and the exact recursions is also used to perform the numerical analysis and the adjustment of encoding parameters. Wang Xiao [4] et al. propose an efficient perfect secure network coding algorithm by using Hash function. Hash function, initial random-number and secret message are adopted to generate random number so as to construct an appropriate transition matrix to improve the safety performance of secret message. The algorithm can improve the encryption system performance in cases of bandwidth without loss. In order to improve the performance of bit error ratio in non-symmetrical two-way relay communications, Li bo [5] et al. propose a combined orthogonal physical-layer network coding in two-way relay communications by adopting orthogonal comprehensive and QPSK modulation. Pei Hengli [6] et al. propose a secure network coding method merged with time-stamp and homomorphic signature which can solve security issues in wireless multi-hop networks. The algorithm introduces RSA-based homomorphic signature scheme, and then another new homomorphic signature scheme based on the time-stamp design is introduced to produce random coefficients of network coding, thus made it is possible to defend pollution attacks and replay attacks simultaneously while maintaining the homomorphic property of the signature. And its validity and feasibility has been proved by experiment [7].

Some scholars at abroad have also achieved some research results for network coding. Z Yi [8] et al. propose outage probability and optimum power allocation for analog network coding, which is a well-known amplify-and-forward (AF)-based bidirectional protocol for a bidirectional network consisting of two different sources and a relay[9]. In this protocol, the two sources exchange information with the help of the relay during two time slots in a half-duplex mode. In addition, an optimum power allocation scheme is proposed, which

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denotes noise function. For the network coding structure which meets
\[ i \in n(S_i), \quad \text{the network lifetime is } e_i. \]

It is assumed that the relay nodes \( n_i \) and \( n_j \) receive the information source \( \tau_i \) and \( \tau_j \), sent out by nodes \( x_i \) and \( x_j \), and the expression equation of the relay nodes is shown as follows:

\[ Q(\tau) = H(\tau) \cdot Y(\tau) + \mu G(\tau) \]  

(3)

where \( H(\tau) \) denotes encoding function; \( Y(\tau) \) denotes signal superposition function; \( \mu \) denotes channel gain factor and \( G(\tau) \) denotes signal gain function. For example, the collection of forward hop node and backward hop node of \( S_i = \{(j, i, k), (m, i, n)\} \) is \( p(S_i) = \{j, m\} \) and \( n(S_i) = \{k, n\} \), respectively.

Based on the equation (3), the received signal of relay nodes \( n_i \) and \( n_j \) are respectively obtained, as shown in Equation (4):

\[ \tau(n_i) = \frac{\sum_{j=1}^{n} \exp \left( \frac{\tau_i}{2} \right)}{2\pi d(i)} + \exp \left( G(\tau_i) \right) \]  

(4)

\[ \tau(n_j) = \frac{\sum_{j=1}^{n} \exp \left( \frac{\tau_j}{2} \right)}{2\pi d(j)} + \exp \left( G(\tau_j) \right) \]  

(5)

It is assumed that the source nodes \( x_i \) and \( x_j \) send information source \( \tau_i \) and \( \tau_j \), and they are denoted as:

simultaneously minimizes the outage probability and maximizes the total mutual information of the analog network coding protocol. A new efficient network coding-based opportunistic routing protocol (CCACK) [10] is proposed by D Koutsonikolas et al.. According to credit-based rate control algorithm, CCACK cumulative coding acknowledgment scheme allows nodes to acknowledge network-coded traffic for their upstream nodes in a simple way, which is without loss rates and with negligible overhead obliviously. In this paper, we would like to emphasize that compared to earlier work, our proposed algorithm relies on a active mechanism, which is the key to extend the optimality result in the network coding. Earlier techniques are mainly based on exploiting the coding analytic properties without further conditions on the discount factor or transition, while the multi-channel sensing is adopted in paper to solve the coding problem. Therefore, we have considered an optimal multi-channel sensing problem which is of fundamental interest involving opportunistic communications over multiple channels.

The rest of this paper is organized as follows. In Section two, the network model used in paper, the network coding of single-hop network, and the system model are listed. The multi-channel sensing is formalized and described in Section three. The experimental results of our proposed algorithm are shown in Section four, and the conclusion is made in Section five.

II. SYSTEM MODEL.

It is assumed that data is transmitted by the information source from source node to destination nodes in the form of direct transmission or node relay. The node cannot carry on the receiving data and sending data if the semi-duplex work form is performed when relay transmission is adopted. When the information is sent to a relay node by source node, the network coding is adopted by the relay node for information. The destination node decodes this information after they arrive at destination node suddenly, and gets raw information [11-12]. Nevertheless, the dual hop network \((j, i, k)\) and \((n, i, m)\) cannot be encoded at the same time. In addition, it is the total number of bits in one single block [13].

The source node needs to identify the set of coded modules from different packets, since decoding can only be performed with coded modules from the same packet. For this purpose, a sequence number should be used to uniquely identify a packet. Due to the multi-channel diversity, this is usually not an issue in physical layer designs [14]. Let us assume that the information source in the communication network is denoted by vector set as \( F = \{\tau_1, \tau_2, \cdots, \tau_n\} \), where \( X = \{x_1, x_2, \cdots, x_n\} \) denotes the source node of communication network; \( N = \{n_1, n_2, \cdots, n_n\} \) denotes the relay node of communication network and node \( a \) denotes terminal. It is assumed that the source nodes \( x_{i} \) and \( x_{j} \) send information source \( \tau_{i} \) and \( \tau_{j} \), and they are denoted as:
where \( d(i) \) and \( d(j) \) denote the Euclidean distance from the source nodes \( x_i \) and \( x_j \) to relay nodes \( n_i \) and \( n_j \), respectively; \( G(\tau_i) \) and \( G(\tau_j) \) denote the signal gain function of relay nodes \( n_i \) and \( n_j \), respectively. After the relay node receives signals, the maximum likelihood decoding is conducted on the signals, and then the decoded signals are obtained:

\[
\tau(n_i) = \arg \min \left\{ \sum_{k=1}^{n} p_k \left[ \sum_{t=1}^{t_i} \tau_t - \tau_i \right] \right\}^{2}
\]

\[
-\sum_{k=1}^{n} \sum_{t=1}^{t_i} \tau_t - \tau_i
\]

\[
\tau(n_j) = \arg \min \left\{ \sum_{k=1}^{n} p_k \left[ \sum_{t=1}^{t_j} \tau_t - \tau_j \right] \right\}^{2}
\]

\[
-\sum_{k=1}^{n} \sum_{t=1}^{t_j} \tau_t - \tau_j
\]

where \( t_1 \) and \( t_2 \) denote the decoding time required by the relay nodes \( n_i \) and \( n_j \), respectively.

Advantages and in accordance with the purpose of the present researches, a method is adopted to receive data in multi-channel sensing system, which performs a random linear decoding with the selected coded blocks to restore a packet. Minimizing sample as cost, the coding effect of the relay node is sensed so that the network can learn from the coding effect of relay node and avoid selecting the relay node with poorer coding effect. The workflow is shown in Figure 1.

It is assumed that \( i \) source nodes will send signals to terminal \( a \) and the selectable relay nodes have \( z(\tau z = i) \). In addition, assume \( i \) source nodes provide \( \tau_1 \) information to examine the coding effect of the relay. We adopt cost function to express the cost of information paid for the relay nodes selected randomly by the \( i \) source nodes:

\[
f(\tau_i) = \sqrt{\sum_{k=1}^{n} \Omega(k) \cdot \tau_i} \cdot \exp \left( \frac{i \cdot \tau_i}{\sum_{k=1}^{n} d(k) \cdot \psi} \right)
\]

\[
\text{If } i \text{ source nodes can select appropriate relay nodes from the } j \text{ relay nodes, the probability is:}
\]

\[
p(i) = \log_2 \left( \frac{1}{i} \right) \cdot \begin{bmatrix}
x_i & x_{i-1} & 0 & 0 \\
0 & 0 & x_{i-2} & x_{i-1} \\
0 & x_{i-3} & x_{i-2} & x_{i-1}
\end{bmatrix}
\]

When \( i \) source nodes can select appropriate relay nodes, the cost of information is written as follows:

\[
f(\tau_i) = \sqrt{\sum_{k=1}^{n} \Omega(k) \cdot \tau_i} \cdot \exp \left( \frac{i \cdot \tau_i}{\sum_{k=1}^{n} d(k) \cdot \psi} \right)
\]

\[
\times \sqrt{2\pi} \cdot \frac{1}{1-p(i)}
\]

In order to select appropriate relay nodes for per source node, the average cost of information is \( \frac{f(\tau)}{i} \).

According to the average cost of information and the average coding effect of relay nodes, the selected threshold value of relay nodes is set up. Here the average cost of information has been obtained, so the average coding effect of relay nodes needs to be calculated as follows.

\[
\Theta(\tau_i) = \sqrt{\frac{1}{j} \cdot \sum_{k=1}^{n} \Omega(k) \cdot \tau_i} \cdot \ln \left( \frac{\sum_{k=1}^{n} U(k)}{j} \right)
\]

where \( \sigma \) denotes weighting factor and \( U(k) \) denotes decoding size of relay node.
After obtaining the average coding effect of relay nodes $\Theta(\tau_i)$ and average cost of information of source node, the comprehensive cost threshold value $T$ is shown as follows:

$$T = \Theta(\tau_i) + \frac{i}{\int_{\tau_i}^\infty f(\tau) \, d\tau}$$  \hspace{1cm} (12)$$

When the information used by source node is $\tau_i$, the cost of information of source node and the coding effect of the selected relay node are calculated, and then the comprehensive cost is obtained by the equation (12). Compared with the result with comprehensive cost threshold value $T$, if it is less than the comprehensive cost threshold value, it shows the relay node has better coding effect and the source node can send information to the node so as to encode & decode. Therefore, the multi-channel channel can avoid selecting the relay nodes with poorer coding effect.

B. Active Mechanism

When relay node sends the encoded information to the terminal, the terminal begins decoding. In order to control the decoding error rate effectively and improve the decoding capacity, an active mechanism is adopted to control the decoding error rate. It is assumed that the relay node $n_i$ sends the encoded information $\tau(n_i)$ to terminal $a$, and the decoding error rate is written as follows:

$$p(n_i) = \frac{1}{\omega} \int_{\tau_i}^\infty \frac{m \eta \tau(n_i)}{\omega} \, d\theta$$

$$= \frac{1}{\omega} \eta \tau(n_i) \frac{(m-1)!}{\pi^2}$$  \hspace{1cm} (13)$$

$\omega$ denotes the decoding factor of the terminal, which stands for the decoding capacity of the terminal; $\eta$ denotes the interference that system itself has, which has some affect on the decoding performance.

In order to reduce the decoding error rate, the Lagrangian optimization method [21-24] is adopted to create an optimization function:

$$f(p(n_i)) = \frac{1}{\omega} \int_{\tau_i}^\infty \frac{m \eta \tau(n_i)}{\omega} \, d\theta$$

$$= \int_{\tau_i}^\infty \frac{(m-1)!}{\pi^2} \prod_{k=1}^m \eta \tau(n_k) \, d\theta$$

$$= \frac{1}{\omega} \left( \eta \tau(n_i) \right) \cdot p(n_i) \frac{m!}{\pi^2}$$  \hspace{1cm} (14)$$

The optimization function makes the effect of decoding error rate not only depends on the encoded information of relay node $\tau(n_i)$, but also relates to the last decoding error rate of the terminal.

In order to make a thorough analysis of the influence of network coding on the lifetime, a simple active mechanism model is adopted. This function describes the decoding requirements of network coding with different terminal. For all coding structures $\{S_i\}$ including the sum of $(j,i,k)$ and $(j',i,k'), k \neq j'$, their rate should be less than a certain appropriate value between $h$ and $i$. They should go through $j'$ and the rate encoded packet intercepted by $j$. This function gives the energy restriction. And then, assume the link rate is large enough, and only considers the influence of the distribution of total flow rate on lifetime optimization problem.

Our proposed algorithm can be worked in multi-channel wireless networks [25-27]. In such networks, a node is able to establish connections with two or more upstream nodes through different sub-channels. In general, errors rate can incur on certain bit positions under certain modulation schemes. Under such scenario, the receiver may not be able to collect enough information knowledge for decoding, even after the retransmissions are performed for several times. Intuitively, it should be proposed to take advantage of the diverse error rate over different bit positions to protect certain coded blocks by arranging bits of the blocks on the good bit positions.

In order to minimize the decoding error rate, the equation (14) is minimized and the equation (6) is introduced here. The definition of rate is shown as follows, so we can obtain:

$$\min p(n_i) = \min \frac{1}{\omega} \left\{ \eta \left( \sqrt{\frac{\sum_{k=1}^m \tau_k}{n^2}} \cdot \sum_{k=1}^m \tau_k - t_i \right) \right\}$$

$$= \eta \left( \sqrt{\frac{\sum_{k=1}^m \tau_k}{n^2}} \cdot \sum_{k=1}^m \tau_k - t_i \right) \cdot p(n_i) \frac{m!}{\pi^2}$$

It is observed form the above equation that controlling the transmitted power of source node and reducing the size of the sent information source can achieve the minimization decoding error rate.

IV. EXPERIMENT RESULT AND ANALYSIS

All of the experiments are run under Visual Studio 2010 on PCs with an Intel Core i5 CPU at 3.2GHz and 2 GB memory and adopt the C++ programming language to perform simulation in window 7. There are 20 transmitting nodes and 100 relay nodes in network source. In order to send information, the size of data package is set as 3kbps and the channel loss rate is 5%. The total runtime of the algorithm is 3 hours. It is conducted at the unified platform and same parameter with the literature [8] and [9], where literature [8] proposed by Z Yi et al. is outage probability and optimum power allocation for analog network coding and the literature [9] proposed by D Koutsonikolas et al. is a new efficient network coding-based opportunistic routing protocol through cumulative coding acknowledgment scheme.
Figure 2 shows the proportion of data package with successful coding under the circumstances of different sizes. The purpose of the experiment is to verify the effect of successful coding for the algorithm. If the proportion is higher, it shows the algorithm has better coding effect. It is observed from the figure that in the active mechanism network coding algorithm based on multi-channel sensing, with the growing of data package, the proportion of successful coding reduces gradually, yet it is always higher than both of network algorithms proposed by Z Yi and D Koutsonikolas. When the size of the data package is 10 kbps, the successful coding rate reaches 74%, while those of Z Yi and D Koutsonikolas are only 66% and 69%, respectively. It is easy to see that the lifetime increases as the increase of the number of data packet, but there is no simple relation between lifetime and energy overhead. Thus, we can see that the algorithm based on multi-channel sensing can select the relay nodes with better coding effect and play an excellent role in improving the overall coding effect of network [28-30].

It is observed from the figure that with the increasing of runtime, the overall energy overhead of the three algorithms becomes more and more, where the least energy overhead is our proposed active mechanism network coding algorithm based on multi-channel sensing. Then, the performance of the network lifetime and calculation overhead from the protocol model and physical model will be evaluated. We can see that the algorithm in this paper has some advantages at the aspect of saving energy expenses and compared with the network coding algorithms of Z Yi and D Koutsonikolas, our proposed network coding algorithm in this paper has saved 90J and 67J, respectively.

The figure 4 shows the error rate of algorithm decoding in the simulation process. It is observed from the figure that compared with the network coding algorithms of Z Yi and D Koutsonikolas, the decoding error rate of our proposed network coding algorithm is lower. As a whole, it is apparent that the energy overhead increases as the increase of runtime. The error rate only reaches about 16.5% at the end of simulation, while those of Z Yi and D Koutsonikolas are more than 20%. The reason is that the active mechanism is adopted in the algorithm to control decoding error rate so as to reduce the decoding error rate. This paper mainly researches the lifetime maximization problem by using multi-channel sensing in wireless network coding.

V. CONCLUSIONS

This paper proposes an active mechanism network coding algorithm based on multi-channel sensing so as to increase network coding efficiency, reduce the error rate of network decoding and improve network performance. The multi-channel sensing method selects the relay nodes with better coding effect and avoids the ones with poorer coding effect, so it improves network coding performance. In addition, it also adopts the active mechanism to control the decoding error rate effectively and improve decoding capacity. Aiming at the coding success rate, network overhead and decoding error rate in the experiment, three experiments are performed to verify the performance of network coding algorithm, which show that our proposed network coding algorithm has a very good effect on encoding and decoding processes and can effectively reduce the network overhead.
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