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Network Coding with Multimedia Transmission: A Software-Defined-Radio based Implementation

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***Abstract*—Recently, network coding (NC) has been considered as a breakthrough to improve throughput, robustness, and security of wireless network. Although there have been many theoretical studies on performance of NCs, there have been few experiments with pure NC schematics. This paper presents the first implementation of NC with multiple media transmission, which uses layered coding. The implementation is real-time and based on Software Define Radio (SDR) technique. The experimental results show that, by combining NC and source coding, we can control quality of received images on demand.**

***Index Terms*—Network coding, two-way relay model, software defined radio (SDR), orthogonal frequency division multiplexing (OFDM), multimedia, layer coding.**

I. Introduction

In 2000, network coding (NC) was first introduced by Ahlswede in [1] to improve network throughput. Instead of using the mechanism of "store-and-forward" in traditional scheduling (TS), an intermediate node in NC performs additional computations (coding) on the incoming data and then forward the coded information. In general, there are two ways to obtain NC: Straightforward Network Coding (SNC) and Physical Layer Network Coding (PNC) for a throughput improvement of 33% and 50% over TS, respectively.

The operating schematics of TS, SNC, and PNC are usually based on a simple and popular wireless network, called Two-way Relay Model (TWRM), as shown in Figure 1a. The model has three nodes, namely A, R, and B. The two end nodes (A and B) expect to exchange data with each other via a relay node (R) because of radio range. Now assuming that node A has a packet a and node B has a packet b. In TS scheme, Figure 1b, the network uses the store-and-forward mechanism, it will need 4 time slots totally to communicate. Figure 1c illustrates an example of using SNC, is described in [2] in details. The relay node R needs to wait for receiving both the two packets a and b, and then performs the XOR operation over the two received packets in order to produce a new single packet $a \oplus b$, where $\oplus$ denotes bitwise exclusive OR operation. In the third time slot, node R only has to broadcast the coded packet. The two end nodes can recover their expected packet based on their own packet and the received coded packet. Specifically, A can recover the packet b because $b = a \oplus (a \oplus b)$ and B can recover a because $a = b \oplus (a \oplus b)$. Thus, by applying the network coding method at the relay node, the number of time slots can be reduced to 3, instead of 4 as in the TS scheme. In contrast to the SNC which performs coding arithmetic on digital bit streams after they have been received, PNC, proposed in [3], makes use of the additive nature of simultaneously arriving electromagnetic waves for equivalent coding operation as in Figure 1d. This model consumes only two time slots totally.

Although NC has been widely analyzed and assessed via both mathematical models and simulations, only a few results have been obtained via real-channel implementation. One of the first implementations of NC is in [4], where a simplified version of PNC, called *analog network coding* (ANC), was introduced. The idea of ANC is that relay node simply amplifies and retransmits the superimposed signals it receives without coding. The advantage of ANC is that it is simple to implement. However, the relay amplifies the noise along with the signal before forwarding, and thus causing error propagation. The first successful implementation of PNC with coding is in [5] but the system is offline. The first real-time PNC is introduced in [6], based on USRP N210 with XCVR2450 boards. The main drawbacks of this implementation are the change of the frame format and the powers of data from end nodes at the relay node must be balanced. Another implementation of NC is in [7]. This prototype is for SNC and half-duplex packet switching, based on USRP with RFX2400 daughterboards.

It can be noted that while there exist various challenges of NC [8], one of the benefits of NC is the provision of security at the physical layer when, in the TWRM, the intermediate (relay) node broadcasts a coded signal to both end nodes. Accordingly, SDR implementation of NC at the physical layers are of great benefit for physical-layer security.

This paper proposes: (i) implementation of 3-node NC via TWRM (NC-TWRM) in full-duplex transmission mode based on SDR platform with Blade RF Hardware and GNURadio Companion Software in two time slots totally, (ii) the first experiment of 4-node NC-TWRM with combining source coding and network coding in multimedia transmission.

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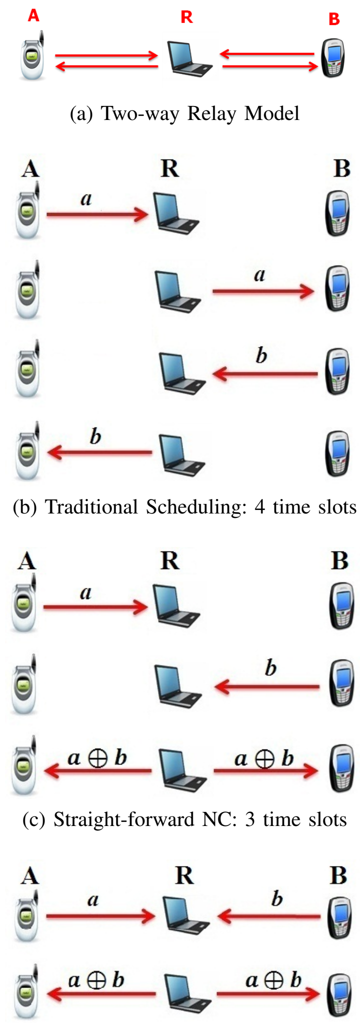


(a) Two-way Relay Model

(b) Traditional Scheduling: 4 time slots

(c) Straight-forward NC: 3 time slots

(d) PNC: 2 time slots

Fig. 1. Conventional forwarding and network coding methods in two-way relay model.

II. Implementation Network Coding via Two-way Relay Model

A. System Model

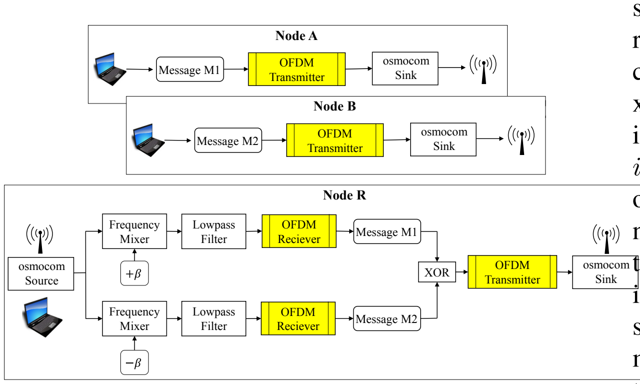


Fig. 2. System Block Diagram

In this section, the purpose is implementation of a real time NC-TWRM system based on SDR in two time slots totally to demonstrate the exchange of two image data files between the two end nodes. The operation at the relay node is XOR on bits without symbols.

To obtain reliable transmission, the challenges are: uplink signals must be distinguished at relay node, time and frequency synchronization, and channel estimation. The solutions respectively are: frequency multiplexing, use preamble part (the structure proposed by the Schmidl-Cox) of OFDM frame and beacon signals, and use pilot part of OFDM.

Besides, FDD mode is used to isolate uplink and downlink transmissions. Node A transmits on frequency $f_0 - \beta$, node B transmits on frequency $f_0 + \beta$, and node R transmits on the other frequency f_1. Node R receives on frequency f_0 with a *wide enough* bandwidth to receive completely both $f_0 - \beta$ and $f_0 + \beta$. As shown in Figure 2, the input signals $f_0 \pm \beta$ at node R go through two branches. In the upper or lower branch, the signals are shifted by an amount of β or $-\beta$ Hz at mixers, and then filtered by low pass filters to retrieve the signals transmitted by node A and node B respectively.

Figure 3 illustrates frequency allocation in our implementation.

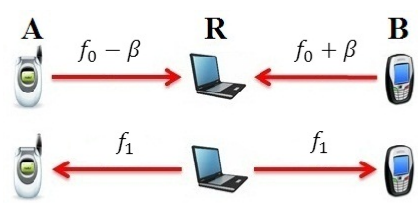


Fig. 3. Frequency Allocation

The messages obtained in the two branches after OFDM demodulation are then combined into a new message by the XOR operation. This new message is then modulated and relayed to A and B.

The network system works in *sessions*. The relay node first broadcasts a beacon message to tell the two end nodes the start of a session. When a session starts, each end node (A and B) loads N native packets and stores them in a buffer. After that, a checking index i runs from 0 to $N-1$. At each value of i, the end node checks whether it has received the corresponding i-th xored packet from the relay or not. If yes, the checking index increases one; if no, the end node transmits the i-th native packet and then the checking index increases one. If the checking index $i = N$, but the end node has not yet received all N xored packets, it will be returned to zero ($i = 0$). Of course, for the first run of the index i through the buffer, the end node certainly has to send all the loaded native packets. Thus, this operating mechanism allows the end nodes to proceed to the transmission of the next native packet without having to wait for the successful transmission of corresponding xored packet from the relay.

At the relay node, whenever it receives a native packet from one end node, it will check whether the corresponding native packet from the other end node is received or not. If yes, and the xored packet has not yet been created, the relay node will combine the two corresponding native packets into a xored packet and store this xored packet in a buffer; if no, the received native packet is just stored in a buffer. The xored packet is transmitted when it is available. Between sessions, the two end nodes and the relay node have to send some control message to each other so that a new session can be started. A new session is started whenever both end nodes have received all N xored packets.

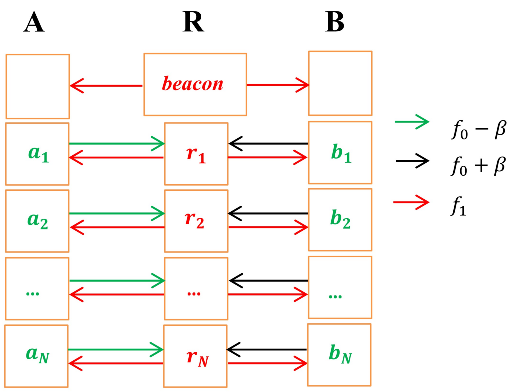


Fig. 4. System Operating Mechanism

B. SDR Implementation

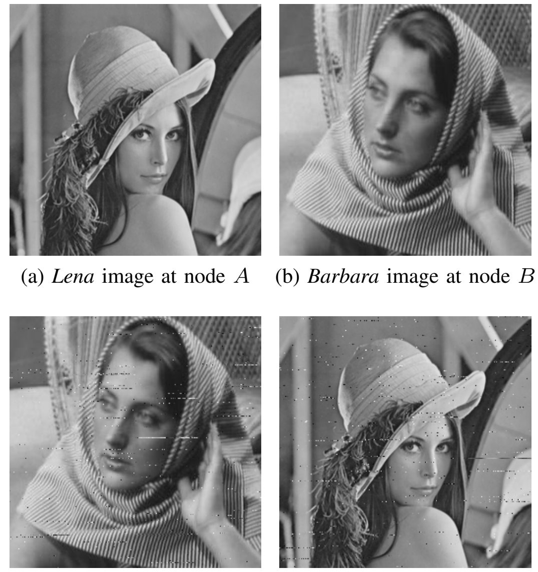
We implement the 3 node NC by using a GNU radio [9] for software and BladeRF kits [10] for hardware. Each node is a commodity PC connected to a BladeRF.

The OFDM Modulator and OFDM Demodulator blocks were developed in the module *gr-s4a* [11].

We develop controller blocks for the two end nodes and the relay node to work with the operating mechanism as described in II-A.

Besides, a Hamming (7,4) code is developed to guarantee communication reliability. This code is able to correct one bit error.

Figure 5 shows the results of implementation of 3 node NC-TWRM based on SDR. In which, through node R, node A and node B want to transmit the Lena (Figure 5a) and Barbara (Figure 5b) images to each other respectively. Size of the images is 256×256 pixels. The results of the transmission are shown in Figure 5c and Figure 5d with bit error rate (BER) of 0.0128 and 0.0122 respectively.



(a) *Lena* image at node A (b) *Barbara* image at node B

(c) Received *Barbara* image at node A, BER $= 0.0128$ (d) Received *Lena* image at node B, BER $= 0.0122$

Fig. 5. Transmitted and Received Images by 3 node NC-TWRM

III. Joint Source-Network Coding

Based on the NC implementation using the two-way relay model as described in Section II, the network is extended with 4 nodes and implement joint source-network coding for showing the usefulness of NC for multimedia transmission.

A. System Model

1) Source Coding: Here, the layered coding (LC), one type of source coding which is widely used in multi-media, is considered in this system model. It generates one based layer and some n enhanced layers. The based layer is the most important layer and essential for data stream to be recovered. Without receiving the based layer, the data stream cannot be recovered since the other enhanced layers depend on the content of based layer. The enhanced layers are to improve the quality of the data stream. However, the first enhanced layer depends on the base layer and each enhanced layer $n+1$ depends on enhanced layer n. Thus a certain layer n can only be applied if $n-1$ layers were already applied. Hence, data streams which uses LC coding can be interrupted whenever one of the layers is missed, at least.

2) 4-node Network Coding System Model: This section introduces a wireless network model with 4 nodes as illustrated in Figure 6. This network system

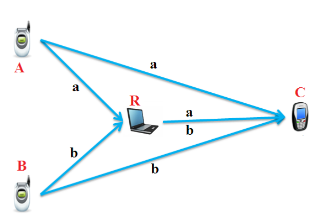
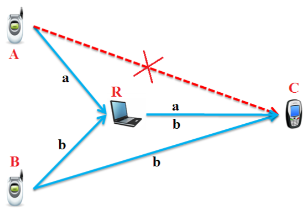


Fig. 6. A 4-node Wireless Network Model.

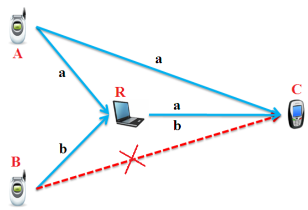
contains 4 nodes namely A, B, C, and R, in which A and B are two source nodes, C is destination node and R is relay node. Both A and B want to send data to

C and they have direct links to C. Node R is added to the system and works as a relaying station with the aim of assisting the data transmission of A and B to C. Node R will relay every packet it received to node C. The addition of node R to the system is to improve the possibility of receiving data packets at C in case of direct-link lost between A and C (link A-C) or between B and C (link B-C).

Consider the situation in which the above 4-node network model employs only traditional relay mechanism. Suppose that one of the two direct-links (A-C or B-C) is lost, Figure 7. The links A-R, B-R, and R-C are supposed to be stable. It can be seen that, thanks to the addition of a relaying station (node R), C can still receive packets transmitted from A and B.



(a) Direct-link A-C lost



(b) Direct-link B-C lost

Fig. 7. 4-node network model with traditional relaying method.

Now, consider the 4-node network model with network coding method as shown in Figure 8. Node R will perform network coding on two packets it received (a and b) to create a new packet, which is $a \oplus b$, and then forward this new packet to C.

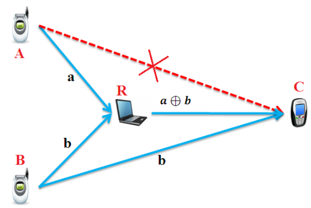
Suppose that the link between A and C (A-C) is lost as in Figure 8a. At node C, based on the packet b received directly from B and the xored packet received from R, the packet a can be recovered by the formula $a = b \oplus (a \oplus b)$. Similarly to the case of B-C lost, the packet b can be recovered by the formula $b = a \oplus (a \oplus b)$. Thus, with the supposition that only one of the two direct-links is lost and the network makes use of network coding method, node R **does not need to know which direct-link is lost**, node R only has to relay the xored packet to C and still insures that C can recover both a and b. While for the case of using traditional relay mechanism, node R has to transmit both a and b since it does not know which direct-link is lost.

3) 4-node Joint Source-Network Coding Model: The source coding (at A and B) are combined with network coding (at R) as shown in Figure 9.

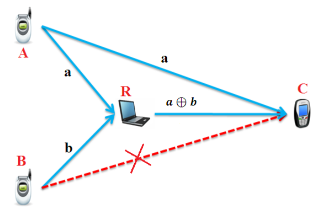
Assume that the direct-link B-C is lost. Each source node (A or B) transmits a layer. Node R performs network coding over the two received packets (a and b) to create a new coded packet c as follows:

$$c = a \oplus \kappa b, \tag{1}$$

where $\kappa \in \{0, 1\}$ is a quality controlling factor at R node.



(a) Direct-link A-C lost



(b) Direct-link B-C lost

Fig. 8. 4-node network model with network coding method.

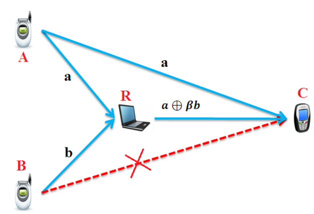


Fig. 9. Network coding with source coding in 4-node network model

We consider two cases:

Case 1: Node R does not have any information about packet b, meaning that b is considered as a normal data packet, κ is set to be 0 or 1 with equal probabilities.

Case 2: Node R has information about packet b, meaning that R knows the packet b is of a layer and essential for the decoding process at C, the parameter κ is set to be 1. This is to make a **priority** for packets transmitted from B.

Figure 10 illustrates the frequency allocation of the 4-node network model. The two source nodes A and B transmit on frequencies f_1 and f_2, respectively. Node R receives on f_1, f_2, and transmits on f_3. Since the link B-C is supposed to be lost, node C can only receive signals on f_1 and f_3. In addition, node C makes use of a controlling channel f_4 to transmit control messages to A and B. Packets transmitted from A and B will be combined into a xored packet to be relayed on f_3. All nodes in the network system apply the OFDM modulation and demodulation techniques.

This 4-node network system also works in *sessions*. A session is started when node C sends a control message on f_4 to nodes A and B. Whenever the control message is received, end nodes (A, B) will load N packets and then store them in a buffer. After that, end nodes will send N packets continuously until receiving the next control message for the next session. At node R, received packets are used to create a xored packet and the created packet is sent to node C.

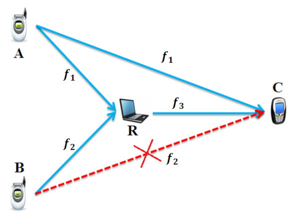


Fig. 10. Frequency allocation in 4-node network model

B. SDR Implementation

To implement the system based on SDR, LC is first performed in MATLAB to generate the text files containing the layers. For simplicity, LC in this model is implemented with only two layers (the based layer and one enhanced layer). Then, the controller blocks of source nodes (A and B) in GNU radio software load the text files corresponding to the layers and send them (B loads the base layer, and A loads the other enhanced layer). The coded data in this experiment is a grayscale image of *Lena*. The based layer is generated by filtering the image with a lowpass filter, and the enhanced layer is generated by having the original image subtracted by the based layer. A block in GNU radio for decoding at the destination node (C) is built, so that the image can be recovered directly in GNU radio software. About hardware, in this model, each source node (A or B) is a commodity PC connected to a BladeRF kit while PCs of relay node R and destination node C are connected to two BladeRF kits.

(a) Decoded Image without information about source coding, $\text{BER} = 0.2673$

(b) Decoded Image with information about source coding, $\text{BER} = 0.0108$

Fig. 11. Decoded Images at node C by LC

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Experimental results are shown in Figure 11. In detail, Figure 11a presents the implementation result of 4-node NC-TWRM without information about the source code while Figure 11b shows that with information about source code. BERs are 0.2673 and 0.0108, respectively. It is summarized that the proposed 4-node NC model can be used not only for relaying without knowing of the lost link but also for controlling data quality by combining source coding and NC.

IV. Conclusions

In this paper, we have proposed two models of implementation of the network coding for multimedia transmission based on SDR: 3-node NC-TWRM and 4-node NC-TWRM. The real-time implementation in full-duplex transmission mode is overcome by using advanced methods. BERs of the received images are acceptable. Network coding and Software Define Radio are new trends, which need developed in future communications.

Acknowledgment

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