On the Performance of Random Linear Network Coding in Relay Networks

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***Abstract*—We compare the reliability performance gain of Random Linear Network Coding (RLNC) with Automatic Repeat Request (ARQ) for a wireless relay network taking into account overhead and complexity of feedback mechanism as well as overhead due to encoding vector embedded in packet header under RLNC. Our goal is not to propose a new ARQ or RLNC error control protocol, but rather to study the fundamental properties of ARQ and RLNC under condition of finite block sizes. We consider an Enhanced ARQ (ARQ-E) scheme that exploits sender side path diversity between the sender and the relays as well as a Single Path Routing (ARQ-SPR) scheme that uses a hop-by-hop ARQ protocol. The performance metric of interest is reliability gain, the expected number of channel uses per data bit received at the receiver. In the case of AWGN channels, we compare the reliability performance of these protocols with each other and observe the fact that RLNC provides limited performance gains.**

I. Introduction

Network coding (NC) is a promising area of research, proposed as a new paradigm to ensure efficient use of network capacity [1]. NC defines a new type of relay scheme that consists of mixing the received information through at each node and forwarding the encoded versions. The classical forwarding schemes that send an exact copy of each received packet over outgoing links link is a very specific case of NC, where coding reduces to copying a packet.

The asymptotic performance of NC, with large packet lengths and large coding block sizes, has been analyzed for different topologies with unicast [2] and multicast [3] flows, and relay channels [4] and the results show a capacity gain under NC. Moreover, it has been shown that network coding improves network reliability by reducing the number of packet retransmissions in lossy networks compared with ARQ baseline protocols [5]–[7]. However, in all of these works the resulting overhead of applying NC in a network has been ignored as packet sizes are assumed to be very large compared to the coding overhead. Moreover, NC has been usually compared with very simple baseline protocols such as ARQ-SPR; however, a more advanced baseline protocol may show better performance.

In this paper, we consider a specific case of Random Linear Network Coding (RLNC) where transmitted packets in the network are random linear combinations of the initial data packets at the source. We compare the reliability gain of RLNC with ARQ for a wireless relay network under practical ("real-world") constraints of finite length packets and a finite coding block size for RLNC. As the asymptotic performance results [4] no longer apply, we need to take into account overhead and complexity of feedback mechanisms as well as overhead due to encoding vector sent along with each packet under the NC approach. We consider an ARQ-SPR scheme that uses a hop-by-hop ARQ protocol to ensure reliable delivery of packets along a path that is set up in advance; and a more advanced ARQ scheme (ARQ-E) that exploits path diversity between the sender and the relays. The performance metric of interest is reliability gain, the expected number of channel uses per data bit received at the receiver. In the case of AWGN channels, we compare the reliability performance of these protocols with each other and observe the fact that RLNC provides limited performance gains.

The rest of this paper is organized as follows. In the next section we introduce our model and our assumptions. The reliability performance of RLNC is derived in Section III. In Section IV we analyze the reliability

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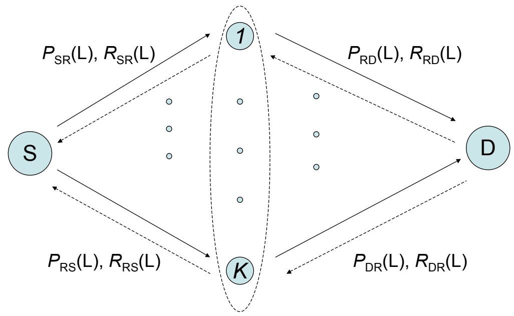

Fig. 1. We consider a single-sender single-receiver relay channel with K relay nodes.

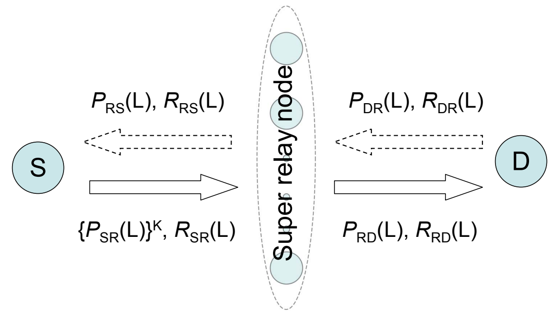

Fig. 2. For the RLNC analysis, we replace the set of relay nodes with a super-relay node.

performance of ARQ-SPR and ARQ-E. Section V evaluates the reliability gain of RLNC versus ARQ-SPR and ARQ-E for different scenarios. We conclude this paper in Section VI.

II. Wireless relay network

Consider a relay channel with a single sender S, a single destination D, and K relay nodes $\{1, ..., K\}$ as depicted in Figure 1. We assume that nodes are not able to send and receive simultaneously and simultaneous reception from multiple nodes is also impossible as it causes collisions. We also assume that packets are communicated over noisy physical layers, where all the sender-to-relay and relay-to-destination channels are iid. Let $\{\mathcal{P}_{SR}(L), \mathcal{P}_{RD}(L)\}$ and $\{\mathcal{R}_{SR}(L), \mathcal{R}_{RD}(L)\}$ be the set of packet loss probabilities and physical layer transmission rates for packets of length L bits transmitted over the sender-to-relay and the relay-to-destination channels, respectively. $\{\mathcal{P}_{RS}(L), \mathcal{P}_{DR}(L)\}$ and $\{\mathcal{R}_{RS}(L), \mathcal{R}_{DR}(L)\}$ are the set of packet loss probabilities and physical layer transmission rates over the reverse channels. For now, we simply assume that these sets are given. In Section V we consider how to determine these sets.

We consider the reliability performance of three different mechanisms (RLNC, ARQ-E, and ARQ-SPR) that are used to increase communication reliability by introducing redundancy at the packet layer. These mechanisms are based on the application of ARQ or FEC in a link-by-link fashion. Note that by abstracting a transmission channel with packet loss probability and transmission rate, we already assume a specific way to ensure the reliability of transmissions that consists of transmitting redundancy bits at the physical layer using channel codes. There is clearly a tradeoff between the amount of redundancy transmitted at the physical and packet layers. Since increasing the reliability of a transmission at the physical layer reduces the amount of redundancy required to be sent at the packet layer, to do that we need a stronger channel codes, i.e. more redundancy at the physical layer. Reducing redundancy at the physical layer decreases the reliability of transmissions at the physical layer that increases the expected number of per packet transmission at the packet layer.

In this paper, we are interested to study the total expected number of bits transmitted at the physical interface for each bit of information transmitted from the sender and received at the receiver ($[N]$). In Sections III and VI, we calculate $[N]$ for RLNC ($[N_{RLNC}]$) as well as for ARQ-E ($[N_{ARQ-E}]$) and ARQ-SRP ($[N_{ARQ-SPR}]$). In Section V, we study the cross-layer tradeoff between coding redundancy at the physical layer and redundancy introduced by error control protocols (ARQ and RLNC) at the packet layer.

III. Performance analysis of RLNC Scheme

In this section, we consider the error control performance of RLNC. The sender's goal is to reliably transmit B packets, each of length l_d bits, to the receiver. We consider RLNC over a finite field $_q$, where each coding coefficient is of length $\log_2 q$. Transmissions are carried out in a two-phase block-by-block fashion. In the first phase, the sender broadcasts a sufficient number of coded packets (independent linear combination of original packets) to the relays such that relays together receive at least B coded packets. In the second phase, relays transmit random linear combinations of the received coded packets to the destination. The receiver must receive B "independent" linear combinations of the original packets from relays to perform the decoding process.

For the RLNC analysis, we replace the set of relay nodes with a super-relay node as shown in Figure 2, thus ignoring coordination costs among relay nodes. That is, we assumed that each individual relay has access to all packets transmitted from the sender to the relays,

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which is not true in practice as each relay receives a random subset of these packets. Note that $\mathcal{P}_{SR}(l_d)^K$ is the packet loss probability between the sender and the super-relay and $\mathcal{P}_{RD}(l_d)$ is the packet loss probability over the super-relay to the destination link. Using the concept of a super-relay, we also ignore the complexity of scheduling among the relays using RLNC, hence our analysis provides a lower bound for $\ [N_{RLNC}]$. In [2] a distributed algorithm to determine the optimal number of packets that must be sent by each node in the network to minimize $\ [N_{RLNC}]$ has been proposed that can be used to schedule transmissions in the network; however, it is not clear how this algorithm performs for finite B.

As described earlier, the sender must send an average of $\frac{B}{(1-\mathcal{P}_{SR}(l_d)^K)}$ packets to the relays to insure the reception of B packets by the set of relays represented by the super-relay. In order to reduce the encoding overhead, we assume that the sender uses a deterministic (linear) coding scheme known by all the relays. Thus the overhead per packet sent from the sender to the relays is negligible. Hence, the expected number of channels uses (the number of transmitted bits at the physical interface) to send a bit of information from the sender to the super-relay is

$$\frac{1}{\mathcal{R}_{SR}(l_d)(1-\mathcal{P}_{SR}(l_d)^K)}. \tag{1}$$

The receiver needs to receive B independent linear combinations from the relays to be able to decode the original B packets. Relays must include the encoding vector to each transmitted packet, consisting of the B random coefficients header for linear network coding. This overhead is $B\log_2 q$ bits per packet, hence the length of packets transmitted by the super-relay is $l_p = l_d + B\log_2 q$ bits. The encoding vector included with each coded packet is an element of $V = \ {}_q^B$ that consists of all B-component vectors $(a_1, a_2, ..., a_B)$ where each a_i is an element of $\ {}_q$. V has a cardinality of q^B [8]. When the receiver receives a packet, it checks its encoding vector; if this encoding vector is independent from the encoding vectors of previously received coded packets, it will keep the packet; otherwise the packet will be dropped. The first received packet is always useful at the receiver (i.e. it is not a linear combination of previously-received packets). The second received packet has an encoding vector $v_2 \in V$. v_2 is independent of v_1 if it is not in the one dimensional subspace of V spanned by v_1.

The subspace spanned with v_1, $\{av_1 \mid a \in \ {}_q\}$, has q elements. If the relay that sent v_2 had access to all B packets received by the relays, then the probability that the randomly generated encoding vector of v_2 is independent from v_1 is $\frac{q^B-q}{q^B}$. However, the node sending v_2 has only access to a subset of packets received by the set of relays represented by the super relay. Moreover, this node is not aware of packets received at other relay nodes and the set of packets received at this node is not completely independent from what is received by other relays. Thus $\frac{q^B-q}{q^B}$ is an upper bound on the probability that v_2 be useful at the destination. Assuming that coded packets sent by relays are iid, the expected number of transmission to receive the second useful packet at the receiver is lower bounded by

$$\frac{1}{(\frac{q^B-q}{q^B})}\frac{1}{(1-\mathcal{P}_{RD}(l_p))}$$

where $\frac{1}{1-\mathcal{P}_{RD}(l_p)}$ is the expected number of transmissions for each packet transmitted by the super-relay and received by the receiver.

Following a similar argument, the third received coded packet is useful for the decoding process at the receiver with a probability that is upper bounded by $\frac{q^B-q^2}{q^B}$ as q^2 is the size of subspace spanned by v_1 and v_2. Hence $\frac{q^B}{q^B-q^2}\frac{1}{(1-\mathcal{P}_{RD}(l_p))}$ is a lower bound for the expected number of transmissions from relays to the destination to receive the third independent linear combination at the destination. In general, after receiving the i-th independent linear combination, the number of vectors in the space spanned by these first i received independent vectors is q^i. Thus, the probability that the next coded packet is useful at the destination is upper bounded by $\frac{q^B-q^i}{q^B}$, i.e. the expected number of transmission is lower bounded by $\frac{q^B}{q^B-q^i}\frac{1}{(1-\mathcal{P}_{RD}(l_p))}$. Summing over all transmissions from relays to destination (to receive B independent linear combination at the destination),

$$\frac{1}{B(1-\mathcal{P}_{RD}(l_p))}(1+\sum_{j=1}^{B-1}\frac{1}{1-q^{-j}})$$

is a lower bound for the expected number of per packet transmission at the packet layer between the super-relay and destination. Hence, the expected number of channels uses to send a bit of information from the super-relay to the destination is lower bounded by :

$$\frac{l_p}{l_d\mathcal{R}_{RD}B(l_p)(1-\mathcal{P}_{RD}(l_p))}(1+\sum_{j=1}^{B-1}\frac{1}{1-q^{-j}}). \tag{2}$$

Finally, the destination sends an ACK to the relays when it receives B independent linear combinations from

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the relays. As we are interested in a lower bound on $[N_{RLNC}]$ we ignore this feedback overhead.

From (1), and (2) we have :

$$[N_{RLNC}] \geq \frac{1}{\mathcal{R}_{SR}(l_d)(1-\mathcal{P}_{SR}(l_d)^K)} + \frac{l_p(1+\sum_{j=1}^{B-1}\frac{1}{1-q^{-j}})}{l_d B \mathcal{R}_{RD}(l_p)(1-\mathcal{P}_{RD}(l_p))}. \quad (3)$$

This bound is tight for large B and q.

IV. Performance analysis of ARQ based protocols

In this section, we consider the performance of two ARQ protocols; ARQ-SPR and ARQ-E. Under ARQ-SPR, packets are routed along a path that is set up in advance to the destination. Using this protocol, the sender and a relay, selected by the sender in advance, use hop-by-hop ARQ to ensure the reliability of transmission to their downstream nodes. In the ARQ-E protocol, the sender broadcasts a packet over the channel and retransmits the packet until it receives at least one ACK from a relay. The relay that successfully transmits its ACK is the responsible to forward the packet to the destination. The selected relay transmits the packet to the destination until it receives ACK from the destination. These two protocols require that each packet be equipped with a sequence number to distinguish it from other packets at the receiver. We assume that transmission are carried in a stop-and-wait fashion, hence the corresponding overhead is negligible.

We first study the performance of ARQ-E protocol. Let l_d be the length of a data packet and l_a the length of and ACK, both in bits. Note that as a data packet requires one unit of time to be transmitted an ACK packet would be transmitted in $\frac{l_a}{l_d}$ units of time. When the sender transmits a packet, an average of $K(1-\mathcal{P}_{SR}(l_d))$ relays receive the packet. Since the set of relays that receive the packet is not deterministic, each relay that receives it must return an ACK to the sender. We use a TDMA-based scheme with K time slots to schedule ACK transmissions, where each relay transmits in a time slot that is known "*a priori*" by all relays as well as the sender. From the perspective of the sender, a packet is lost if the packet itself or the corresponding ACK is lost. Consequently, the overall probability of losing a packet or its ACK is $\mathcal{P}_1 = (1-(1-\mathcal{P}_{SR}(l_d))(1-\mathcal{P}_{RS}(l_a)))^K$. Thus

$$\frac{1}{1-\mathcal{P}_1}$$

is the average number of packets transmitted by the sender. As explained before, for each packet transmitted by the sender an additional $k\frac{l_a}{l_d}$ time units are required for ACKs. Taking into account the ACK overhead, the expected number of channel uses for a bit of information transmitted by the sender and received by the selected relay is

$$\left[\frac{1}{\mathcal{R}_{SR}(l_d)} + \frac{Kl_a}{l_d\mathcal{R}_{RS}(l_a)}\right]\frac{1}{1-\mathcal{P}_1}. \quad (4)$$

In the ARQ-E protocol, the sender sends a message to the node that successfully transmitted its ACK, indicating that this node is responsible for forwarding the packet to the destination. In order that the transmission of this relay selection message be reliable, it is transmitted c consecutive times. This message is at least $\log_2(K)$ bits. Thus $(1-\mathcal{P}_{SR}(\log_2(K)))^c$ is the probability that at least one of these transmitted messages is received by the selected relay. The expected number of channel uses to transfer this message from the sender to the selected relay is

$$\frac{c\log_2(K)}{l_d\mathcal{R}_{SR}(\log_2(K))}. \quad (5)$$

The selected relay forwards the packet to the receiver and continues transmitting packets until the time that it receives an ACK from the receiver. $\mathcal{P}_2 = 1-(1-\mathcal{P}_{RD}(l_d))(1-\mathcal{P}_{DR}(l_a))$ is the probability that the relay does not receive an ACK for each transmission. Hence, the expected number of channel uses for a bit of information transferred from the selected relay to the destination is

$$\left[\frac{1}{\mathcal{R}_{RD}(l_d)} + \frac{l_a}{l_d\mathcal{R}_{DR}(l_a)}\right]\frac{1}{1-\mathcal{P}_2} \quad (6)$$

where $\frac{l_a}{l_d\mathcal{R}_{DR}(l_a)}\frac{1}{1-\mathcal{P}_2}$ is the ACK overhead. Finally, the relay must acknowledge the sender that packet has been delivered successfully to the destination. Similar to the previous case we consider that this destination-to-sender message be transmitted c consecutive times. Let l_m be the length of these message, then this message is received by the destination with a probability greater than $(1-\mathcal{P}_{SR}(l_m))^c$ and the expected number of channel uses is

$$\frac{cl_m}{l_d\mathcal{R}_{SR}(l_m)}. \quad (7)$$

Note that l_m could be very small.

From (4), (5), (6), and (7) we have :

$$\begin{aligned}[N_{ARQ-E}] = & \left[\frac{1}{\mathcal{R}_{SR}(l_d)} + \frac{Kl_a(1-\mathcal{P}_{SR}(l_d))}{l_d\mathcal{R}_{RS}(l_a)}\right]\frac{1}{1-\mathcal{P}_1} \\ + & \left[\frac{1}{\mathcal{R}_{RD}(l_d)} + \frac{l_a}{l_d\mathcal{R}_{DR}(l_a)}\right]\frac{1}{1-\mathcal{P}_2} \\ + & \frac{c\log_2(K)}{l_d\mathcal{R}_{SR}(\log_2(K))} + \frac{cl_m}{l_d\mathcal{R}_{RS}(l_m)}.\end{aligned} \quad (8)$$

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An ARQ-SPR scheme that uses a hop-by-hop ARQ protocol is a specific case of ARQ-E. In this case the actual number of relays that participate in the relaying process is one, i.e. :

$$\begin{aligned}[N_{ARQ-SPR}] &= \left[\frac{1}{\mathcal{R}_{SR}(l_d)} + \frac{l_a(1-\mathcal{P}_{SR}(l_d))}{l_d\mathcal{R}_{RS}(l_a)}\right]\frac{1}{1-\mathcal{P}_1'} \\ &+ \left[\frac{1}{\mathcal{R}_{RD}(l_d)} + \frac{l_a}{l_d\mathcal{R}_{DR}(l_a)}\right]\frac{1}{1-\mathcal{P}_2'} \\ &+ \frac{cl_m}{l_d\mathcal{R}_{RS}(l_m)}\end{aligned} \tag{9}$$

where $\mathcal{P}_1' = 1-(1-\mathcal{P}_{SR}(l_d))(1-\mathcal{P}_{RS}(l_a))$ and $\mathcal{P}_2' = 1-(1-\mathcal{P}_{RD}(l_d))(1-\mathcal{P}_{DR}(l_a))$. Note that as the relay has been selected in advance by the sender, we do not require any relay selection message.

V. Evaluation Results

In this section we compare the reliability performance of RLNC with ARQ-E and ARQ-SPR (given by equations (3), (8), and (9)) where transmissions are carried over AWGN channels. We use Theorem 3 in [9] (see below) to determine the set of packet loss and physical layer transmission rates for packets with length L bits transmitted over the channels using optimal forward error mechanisms at the physical layer.

Theorem 1: In a Gaussian channel with peak power constraint S and noise variance N, the maximum possible rate of codebooks that achieve a probability p of codeword error while using codewords of length n (for a data packet of length L), i.e. $R_{NA}(n,p)$, satisfies

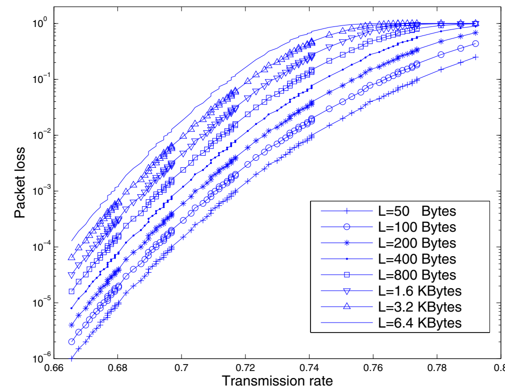
$$R_{NA}(n,p) = \frac{L}{n} = C - \frac{\Phi^{-1}(p)}{\ln(2)}\sqrt{\frac{S}{n(N+S)}} + o(\frac{1}{\sqrt{n}}), \tag{10}$$

where

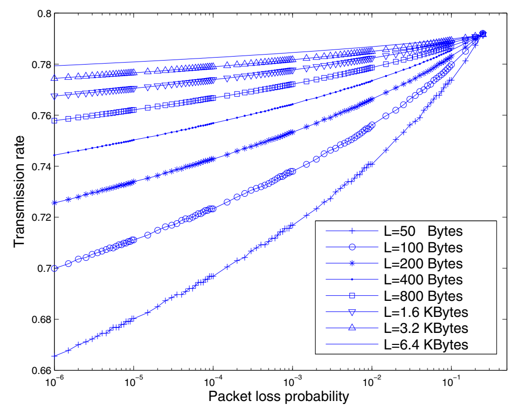
$$C = \frac{1}{2}\log_2\left(1+\frac{S}{N}\right)$$

is the capacity of the channel and and $\Phi(x) \equiv \int_x^{\infty} \exp^{-t^2/2} dt$.
□

We consider two scenarios. In the first scenario, each packet is divided into segments of length l_s where the physical layer is optimally designed to transmit a segment. Hence we can use Theorem 1 to determine the set of packet loss probabilities and transmission rates. Let $(\mathcal{P}_{seg}, \mathcal{R}_{seg})$ be that set, then a packet of length l_d would have similar transmission rate but a packet loss probability equals to $1-(1-\mathcal{P}_{seg})^{\alpha}$ where $\alpha = \frac{l_d}{l_s}$. This is the case in many practical communication systems such as WiFi and UMTS [10]. Note that in this case the packet loss probability increases as l_d increases.



(a) The first scenario with $l_s = 50$ bytes.



(b) The second scenario.

Fig. 3. Packet loss probabilities versus transmission rates for different packet lengths.

In the second scenario, we consider a more advanced physical layer that is optimal for any input packet length l_d, i.e. Theorem 1 can be directly applied to determine the set of packet loss probability and transmission rate for a given l_d. It is worth noting that this scenario is typically basis for the performance analysis of RLNC as it is always assumed that changing the length of transmitted packets does not affect the related transmission loss probabilities [4].

For the sake of simplicity, we show results for a symmetric scenario where the received SNR is 3dB on all channels. See [11] for scenarios with different SNRs. Figures 3(a) and 3(b) depicts packet loss probability versus transmission rate for different l_d's for the first and second scenarios, respectively. We consider segments of size $l_s = 50$ bytes in the first scenario. Similar curves are provided for packets of length $l_p = l_d + B\log(q)$ transmitted from the super-relay to the destination using

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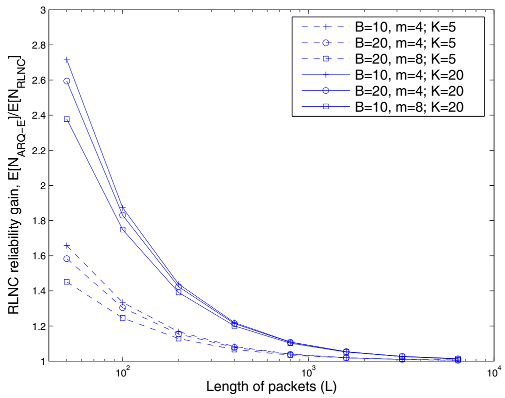
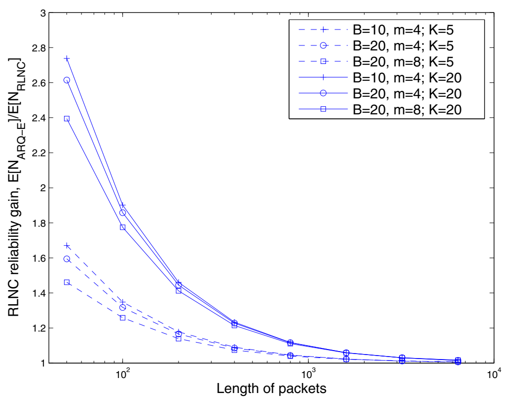
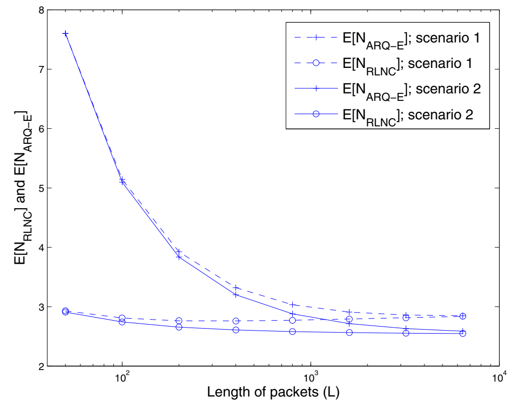


(a) The first scenario

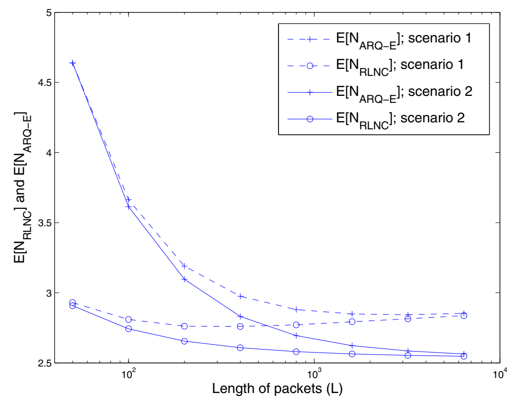


(b) The second scenario

Fig. 4. Reliability gain of RLNC versus ARQ-E.



(a) A network with 5 relay nodes.



(b) A network with 20 relay nodes

Fig. 5. Comparing $[N_{ARQ-E}]$ with $[N_{RLNC}]$ in scenario 1 and 2 for $B = 20$ $m = 4$

RLNC. Note that $C = 0.7913$ is the capacity of an AWGN channel with $SNR = 3dB$. Using these curves, for a given packet length l_d and for each protocol we find the set of packet loss probabilities and transmission rates over links in the network that minimize $[N]$.

We show the results for $l_a = 50$ bits. We also assume that the ACK loss probability is very low, about 0.005, based on strong FEC code at the physical layer. From Theorem 1, the physical layer transmission rate to transmit an ACK is 0.663. For the sake of simplicity, we assume that the relay selection and the destination-to-sender messages also have a length of 50 bits and have the same packet loss probability and transmission rate as an ACK. We set $c = 3$ to quarantine the reliability of transmission of routing request packets, as discussed in the previous section, greater than $(1 - 1.25 \times 10^{-7})$.

We define the **reliability gain** of network coding over ARQ-E algorithm proposed in section IV as

$$Reliability\ Gain = \frac{[N_{ARQ-E}]}{[N_{RLNC}]}.$$

In Figure 4(a) we have the reliability gain of RLNC for $K = 5$ and 20 and for different B and $q = 2^m$ for the first scenario. As can be seen, for $l_d = 50$ bytes the reliability gain of RLNC is approximately 2.8 for $K = 20$ and not more than 1.7 for $K = 5$. This gain decreases as the length of transmitted packets increases. In particular for packets larger than 1000 Bytes the gain is not higher than 1.1. RLNC exhibits similar gain in the second scenario as illustrated by Figure 4(b). Hence, for packets of size 1 KByte, which is the size of an internet packet, or larger there is almost no gain of using RLNC. Note that in this paper we provide a lower bound on $[N_{RLNC}]$, ignoring the scheduling and coordination

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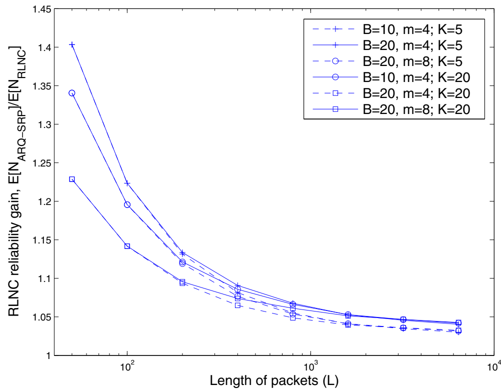

Fig. 6. Reliability gain of RLNC versus ARQ-SPR, the first scenario.

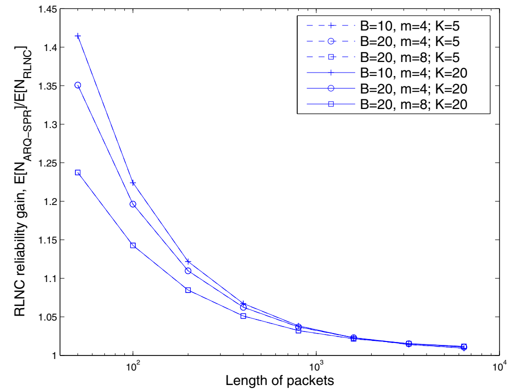

Fig. 7. Reliability gain of RLNC versus ARQ-SPR, the second scenario.

cost among relay nodes, thus the real reliability gain of RLNC might be even less than what we showed here. As stated before, for small size packets, e.g. voice packets, the RLNC reliability gain is large; however, RLNC based approaches suffer from a larger end-to-end communication delay that makes them less interesting for real time traffics.

In Figures 5 we compare the absolute performance metrics $[N_{ARQ-E}]$ and $[N_{RLNC}]$ in scenarios 1 and 2. We show the results for the case that $B = 20$ and $m = 4$. We see that in scenario 1, RLNC show the best performance for $l_d = 200$ bytes while for ARQ-E the best packet length is 3200 bytes. In Scenario 2, both the protocols show a better performance as l_d increases. Hence if we have an advanced physical layer as described in scenario 2, then to reduce the total redundancy transmitted in the network we must increase the length of transmitted packets, and asymptotically, for large l_d, we have

$$[N_{ARQ-E}] = \lim_{B,q\to\infty} \quad [N_{RLNC}] = \frac{2}{C} = 2.527.$$

where l_d growths faster than $B \log q$.

Finally we compare the reliability gain of RLNC versus ARQ-SPR, $\frac{[N_{ARQ-SPR}]}{[N_{RLNC}]}$, in scenarios 1 and 2 where $[N_{ARQ-SPR}]$ is given by equation (9). We show the results in Figures 6 and 7. We see that for small size packets, ARQ-SPR shows better performance compared to ARQ-E (as depicted in Figures 4(a) and 4(b)) as ARQ-E must contend with the scheduling overhead. For large packet sizes, in particular larger than 1000 bytes, ARQ-E outperforms ARQ-SPR as the scheduling overhead is negligible comparing to the retransmission overhead of using ARQ-SPR.

VI. Conclusion

We compared the reliability performance of ARQ with RLNC for a relay network. In our analysis, we considered the overhead and complexity of the feedback mechanism as well as the overhead due to the encoding vector sent along with each packet under RLNC. We showed that using a more advanced ARQ protocol we can reach to a performance comparable with RLNC schemes. Moreover, a single routing path scheme, that does not need a complex scheduling as ARQ-E and has a negligible overhead per each transmitted packet compared to RLNC, shows fairly the same performance as ARQ-E and RLNC protocols.

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