Abstract—A turbo network coding based relay model and its decoding method are proposed for the quasi-static fading multi-access up-link channel. In the model a relay assists two mobile nodes simultaneously by forwarding a network coded version of the two interleaved messages. Access Point (AP) performs joint channel and network decoding with signals received from two mobile nodes and the relay. Compared with existing schemes, the proposed turbo network coding scheme has two main contributions: (i) Only parity check bits of two messages are forwarded by relay and they are further XORed together to improve relay efficiency. (ii) The iterative decoding is used in joint network and channel decoding to salvage packets from erroneous signals in the absence of a priori knowledge. Simulation results indicate that the proposed scheme provides up to 1.8 dB gain to the existing scheme in the case of mutual cooperation among mobile nodes.

I. INTRODUCTION

Wireless LANs (WLAN) provide quick access to Internet and are widely deployed in the hotspot areas. However, service areas of WLAN are affected by path loss and fading. Fading is one of the key characteristics that distinguish wireless networks from wired counterparts. It may lead to not only random bit errors but also outage. The classical channel coding techniques that are often used to overcome random bit errors cannot mitigate fading very well.

Spatial diversity, exploiting the property of independent wireless propagation, has been proven to be an effective method to combating fading over wireless channels. Such a consensus has inspired extensive research on relay theory and cooperative communications, both of which exploit the broadcast nature of wireless medium. In the plain relay model, a relay node can amplify/decode and forward the message to reduce the outage probability. A more effective method is to exploit the coded cooperation [1].

The idea of network coding was originally proposed by Ahlswede et al. [2] to enhance the capacity of wired networks. This idea was extended later to wireless networks to enable efficient relay [3]. Most existing network coding schemes focus on bi-directional communications, initially decode-and-forward mainly in the network layer [4], later the physical layer network coding with amplify-and-forward [5], [6], [7]. The common characteristics of these schemes are to exploit a priori knowledge to reduce the number of transmissions and improve the total capacity of the bidirectional path. In spite of its efficiency, physical layer network coding requires strict synchronization among multiple senders and is difficult to implement. A realistic protocol that exploits XOR-based network coding was suggested in [4].

Relay by network coding may also be used for the diversity purpose to reduce outage. Hausl et al. suggested relaying network coded message [8] and decoding the messages by constructing a Parallel Concatenated Convolutional Coding (PCCC) structure [9]. The scheme requires a priori knowledge which is only available in the bi-directional communications. In addition the relay node does not actually XOR (eXclusive OR) bits of different flows. As for the multi-access up-link, Chen et al. proposed the Distributed Antenna System (DAS) to realize the network-layer diversity with a network coding scheme [10]. However channel coding is not considered.

In this paper we study the multi-access up-link communication and propose a turbo network coding model and its decoding method. In the model two mobile nodes broadcast their coded messages to both relay and Access Point (AP) in orthogonal time slots. The relay decodes both messages, performs interleaving, network and channel coding, and forwards the parity check bits. AP performs joint channel and network decoding to recover the two original messages from the three received signals. The proposed scheme has two main contributions: (i) The relay node only forwards the parity check bits. In addition, parity check bits of two messages are XORed together to further improve relay efficiency. (ii) The iterative decoding (or maximal ratio combining) is used in joint network and channel decoding to salvage packets from erroneous signals and improve the reliability in the absence of a priori knowledge. In contrast to [8], in our scheme the relay is more efficient; furthermore the proposed iterative decoding scheme does not depend on a priori knowledge. Compared with [10] where merely network coding is considered, we study joint channel and network coding and perform iterative decoding. When mobile nodes mutually cooperate with each other, the proposed scheme can provide up to 1.8 dB gain to the DAS with network coding scheme [10].

The rest of the paper is organized as follows. We present the turbo network coding model and the preliminary of log-likelihood algebra in Section II. On this basis we propose the decoding scheme in Section III. Then we evaluate its performance by simulation in Section IV. Finally we conclude
the paper with Section V.

II. SYSTEM MODEL AND PRELIMINARY

A. Turbo Network Coding Model

Fig. 1 shows the network model which consists of two mobile nodes A and B, an access point D and a relay node R lying between A/B and D. A and B send two messages to D in two consecutive orthogonal time slots. Each message carries its own addresses and Cyclic Redundant Check (CRC). To reduce error probability at D, R acts as a relay. When the two messages arriving at R both pass CRC check after channel decoding, R encodes them together and transmits a coded message to D. D jointly decodes the two original messages with the three signals received from A, B and R.

In the system unless otherwise specified systematic convolutional codes with channel coding operation $\Gamma(\cdot)$ are used and BPSK modulation is assumed. The original messages from A and B to D are $X_{AU}$ and $X_{BU}$. Each is channel coded according to Eq.(1) and its parity check part is $X_{iC}$.

$$X_i = [X_{iU}, X_{iC}], \quad X_{iC} = \Gamma(X_{iU}), \quad i = A, B$$  

(1)

When R correctly decodes both $X_{AU}$ and $X_{BU}$, it combines the two messages by XOR and get $X_{RU} = X_{AU} \oplus X_{BU}$. Instead of forwarding $X_R = [X_{RU}, \Gamma(X_{RU})]$ as in the conventional network coding scheme, in the proposed scheme R interleaves $X_{RU}$ by the $\Pi(\cdot)$ operation to get $\Pi(X_{RU})$ and only the parity check part $X_R = X_{RC} = \Gamma'(X_{RU}) = \Gamma[\Pi(X_{RU})]$ is actually transmitted over the link RD. Here $\Gamma'(\cdot)$ involves both interleave $\Pi(\cdot)$ and channel coding $\Gamma(\cdot)$.

The coded packets $X_A$, $X_B$ and $X_R$ with bits stream $x_A(t)$, $x_B(t)$ and $x_R(t)$ are respectively transmitted to D. Under BPSK modulation, the modulated signals are

$$\phi_i(t) = 2 \times x_i(t) - 1, \quad i = A, B, R$$  

(2)

Assume three links $AD$, $BD$ and $RD$ in Fig. 1 respectively have channel gains $h_A$, $h_B$, $h_R$ and additive zero-mean Gaussian noise $n_A(t)$, $n_B(t)$, $n_R(t)$. $n_i(t)$ has the same variance $\sigma^2$. Signals $D$ received from A, B and R are shown below

$$s_i(t) = h_i\phi_i(t) + n_i(t), \quad i = A, B, R$$  

(3)

In times of systematic channel coding, signals $s_A(t)$ and $s_B(t)$ each can be divided into two parts, $s_{iU}(t)$ corresponding to information bits and $s_{iC}$ corresponding to parity check bits. $s_R(t)$ only has the part $s_{RC}(t)$.

It is obvious that the proposed turbo network coding scheme in Fig. 1 improves the relay efficiency by avoiding the transmission of information bits at R. Joint channel and network decoding based on the three received signals $s_A(t)$, $s_B(t)$ and $s_R(t)$, proposed in Section III, also reduces packet error probability where D can recover the two original messages $X_{AU}$ and $X_{BU}$ even when both packets cannot be directly decoded.

B. Preliminary of Log Likelihood Algebra

Usually the coded bits $x_i(t)$ has equal probability of being 0 or 1. Then the log-likelihood ratio (LLR) of the received signals can be calculated as follows.

$$L_i(t) = \ln \frac{P(x_i(t) = 1 | s_i(t))}{P(x_i(t) = -1 | s_i(t))} = \frac{2h_i s_i(t)}{\sigma^2}$$  

(4)

LLR can serve as the soft output of a demodulator. LLR of a signal can be calculated by the operation $L(\cdot)$ and a signal can be calculated from its LLR by the reverse operation $L^{-1}(\cdot)$.

When $X_R = X_A \oplus X_B$, LLR of $X_R$ can be estimated from $L_A(t)$ and $L_B(t)$ by following log-likelihood algebra [11].

$$L'_R(t) = L_A(t) \oplus L_B(t) = \ln \frac{\exp(L_A(t)) + \exp(L_B(t))}{1 + \exp(L_A(t) + L_B(t))}$$  

(5)

$$\approx (-1) \cdot \text{sign}[L_A(t)] \cdot \text{sign}[L_B(t)] \cdot \min(|L_A(t)|, |L_B(t)|)$$

Meanwhile the XOR operation has some special property shown in the following equation.

$$X_R = X_A \oplus X_B \iff X_A = X_B \oplus X_R, \quad X_B = X_A \oplus X_R$$  

(6)

Eq.(6) infers that any message is a network coded version of the other two. Then according to Eq.(5) LLR of any signal can be estimated from the other two.

Consider the extreme case where the receiver somehow decoded one message, saying $X_{RU}$. When $x_R(t) = 1$, $L_B(t) = \infty$ and $L_R(t) \oplus L_A(t) = -L_A(t)$. When $x_R(t) = 0$, $L_R(t) = -\infty$ and $L_R(t) \oplus L_A(t) = L_A(t)$. Then from $L_B(t)$ and $L_A(t)$, the LLR of $X_A$ and $X_B$ can be estimated as $L'_A(t)$ and $L'_B(t)$ respectively, as follows.

$$L'_B(t) = (-1)^{x_R(t)} L_A(t), \quad x_R(t) \text{ is a priori}$$  

(7)

$$L'_A(t) = (-1)^{x_R(t)} L_B(t), \quad x_R(t) \text{ is a priori}$$

Eq.(7) indicates that $L_A(t)$ and $L_B(t)$ can be estimated from each other if their XORed sum $X_R$ is already known in the receiver side.

LLR algebra in Eq.(5) enables estimation of the signal of the XORRed message at the risk of utilizing a signal with lower SNR than the original signals. In Eq.(7) the estimated signal has the same SNR as the original signal by exploiting the accurate a priori information. This observation inspires us to design new decoding schemes to further exploit diversity.
III. THE PROPOSED DECODING SCHEME

In the following we discuss the decoding scheme for the proposed model in Fig. 1. Instead of separately decoding each original message, the joint channel and network decoding is performed.

A. Iterative Decoding

D cannot directly decode \( X_{RU} \) as usual since its information bits are not transmitted. In times of reception failure, recovery of \( X_{AU} \) and \( X_{BU} \) by network decoding is impossible without \( X_{RU} \). Fortunately the signal of \( X_R \) can be estimated from signals of \( X_A \) and \( X_B \), as shown in Fig. 3. With the soft output of turbo decoder DEC3, the two original messages can be iteratively decoded in Fig. 2. Therefore in the following we address the decoding of the XORed message and then discuss how to iteratively decode the original messages from erroneous signals.

1) Decoding the XORed Message: Fig. 3 shows the decoding procedure of \( X_{RU} \). Since \( X_{RU} = X_{AU} \oplus X_{BU} \) are network coded information bits, by utilizing the linear property of channel coding and XOR, the order of XOR and channel coding can be exchanged [12].

\[
\Gamma(X_{AU} \oplus X_{BU}) = \Gamma(X_{AU}) \oplus \Gamma(X_{BU}) \quad (8)
\]

Then \( X_R = [X_{RU}, X_{RC}], X_{RC} = \Gamma(X_{RU}) \) is a XORed sum of \( X_A \) and \( X_B \), i.e., \( X_R = X_A \oplus X_B \). LLR of \( X_A \) and \( X_B \) can be respectively calculated according to Eq.(4). Then according to Eq.(5), \( L'_{RC} = [L'_{RU}, L'_{RC}], \) is calculated from \( L_A \) and \( L_B \) and used as an estimation of the normal network coded message \( X_R = [X_{RU}, \Gamma(X_{RU})] \), as shown in Fig. 3(a). Meanwhile \( D \) also obtains \( s_{RC} \), the signal of the parity check part \( \Gamma'(X_{RU}) \) received from \( R \). Since the systematic convolutional code is used, in Fig. 3(b-c) the PCCC structure of \( X_{RU} \) can be formed. Then \( X_{RU} \) can be decoded by the standard turbo decoding [13].

The turbo decoder outputs the decoded message \( X_{RU} \) if the decoding is successful. Otherwise it outputs the soft value \( L'_{RU} \) of \( X_{RU} \). Either of the output will be utilized in the following iterative decoding of the original messages.

2) Iterative Decoding of the Original Messages: By the BCJR [14] or LogMAP [15] algorithms, the soft-input soft-output (SISO) convolutional channel decoder can be implemented and joint detection of the two messages is possible. In Fig. 2 the received signals \( s_A(t) \) and \( s_B(t) \) are directed to the SISO channel decoders DEC1 and DEC2. The turbo decoder DEC3 corresponds to the procedure in Fig. 3. DEC1 and DEC2 also have extra inputs, \( L'_{AU}(t) \) and \( L'_{BU}(t) \), a priori knowledge of the information bits which is initiated to zero. The soft decoding output of DEC1, DEC2, DEC3 are \( L_{AU}(t), L_{BU}(t), \) and \( L_{RU}(t) \) respectively. According to Eq.(5), the extrinsic information \( L'_{BU}(t) = L_{AU}(t) \oplus L_{RU}(t) \) and \( L'_{AU}(t) = L_{BU}(t) \oplus L_{RU}(t) \) are extracted and used as a priori information in the next iteration in DEC2 and DEC1.

B. Simplification of Decoding by Maximal Ratio Combining

The procedure in Fig. 2 can be simplified when the turbo decoder DEC3 correctly decoded \( X_{RU} \). \( D \) locally generates the channel code \( X_{RC} = \Gamma(X_{RU}) \) from \( X_{RU} \) and regards \( X_R = [X_{RU}, X_{RC}] \) as a priori knowledge and utilizes it to help decode \( X_{AU} \) and \( X_{BU} \). According to the LLR algebra in Eq.(7), \( D \) calculates \( L'_A(t) \) as an estimation of \( L_A(t) \) from \( L_B(t) \) and calculate \( L'_B(t) \) as an estimation of \( L_B(t) \) from \( L_A(t) \). Then combining diversity can be applied as follows.

\[
\begin{align*}
L''_A(t) &= L'_A(t) + L_A(t) = (-1)^{x_R(n)} L_B(t) + L_A(t) \quad (9) \\
L''_B(t) &= L'_B(t) + L_B(t) = (-1)^{x_R(n)} L_A(t) + L_B(t)
\end{align*}
\]

Because \( x_B = x_A \oplus x_R \) and \( x_A = x_B \oplus x_R \), under BPSK modulation \( \varphi_B(t) = (-1)^{x_R(n)} \varphi_A(t) \) and \( \varphi_A(t) = (-1)^{x_A(n)} \varphi_B(t) \). With these relationship and Eq.(4), Eq.(9) can be simplified.

\[
\begin{align*}
L''_A(t) &= \frac{2h_B}{\sigma^2} s_A(t) + \frac{2h_A}{\sigma^2} s_A(t) \\
L''_B(t) &= \frac{2h_A}{\sigma^2} s_B(t) + \frac{2h_B}{\sigma^2} s_B(t) \quad (10)
\end{align*}
\]

Eq.(10) is the standard form of maximal ratio combining. Except the noise part it looks as if \( D \) receives another copy of \( \varphi_A(t) \) from \( B \) and another copy of \( \varphi_B(t) \) from \( A \). The two copies of the same message are combined together according to their channel gains. \( L''_A(t) \) and \( L''_B(t) \) are not independent. They contain the same information and have the same SNR. Then iteration becomes unnecessary. From either of the estimated LLR, saying \( L''_A(t) \), the signal \( s'_{RA}(t) \) can be calculated and used as the input of the convolutional channel decoder. If the decoding of \( X_{AU} \) is correct, together with \( X_{RU} \), the other message \( X_{BU} \) can also be correctly decoded by applying Eq.(6).

The simplification by maximal ratio combining can effectively reduce the computation cost. The combination in Eq.(9) can be done either based on LLR of the soft demodulation output or LLR of the soft decoding output. The simulation results indicate that at low SNR the former is a better choice.
Therefore other original message can be decoded. When the network coded message can be decoded by turbo decoding, the turbo decoding method can be supplemented by the turbo decoding. When the turbo decoding process is used, the turbo decoding converges to a solution that is close to the solution that would be obtained by decoding the original messages individually. When one of the original messages can be directly decoded, the turbo decoding can be used.

When one of the original messages can be directly decoded, the turbo decoding method can be performed in a different form, as shown in Fig. 4. Assume without losing generality that the message which D correctly decoded is X_{AU}. Then D can decode the XORed message and perform channel decoding again to get \( \Gamma'(X_{AU}) \). XOR, interleaving and channel coding are all linear. Therefore

\[
\Gamma'(X_{RU}) = \Gamma'(X_{AU}) \oplus \Gamma'(X_{BU})
\]

is also network coded. With the locally generated \( \Gamma'(X_{AU}) \) as a priori and according to Eq.(7), \( L_{BC} \) can be calculated as an estimation of \( \Gamma'(X_{BU}) \) from \( L_{RC} \), the signal of \( \Gamma'(X_{BU}) \). Then in Fig. 4(c-d), a PCCC structure of \( X_{BU} \) can be formed and this message can be decoded with the standard turbo decoding.

According to the above description, when one of the original messages, say \( X_{AU} \), can be directly decoded, the receiver \( D \) has two choices, either to recover the network coded message \( X_{RU} \) by turbo decoding in Fig. 3, or to directly recover the other original message \( X_{BU} \) by turbo decoding in Fig. 4. As shown in Fig. 5 in either case \( s_A \), the signal of the correctly decoded message, is not utilized. In both PCCC structures, the upper row comes from \( s_B \) and the lower row comes from \( s_{RC} \). Though the LLR algebra is involved in different stages, with \( X_{AU}, \Gamma(X_{AU}) \) and \( \Gamma'(X_{AU}) \) as accurate a priori knowledge the operation in Eq.(7) generates an estimated signal with the same SNR. The signals in both PCCC contain the same information. Therefore the two procedures actually have the same decoding probability, as can be verified by simulation.

\[
X_w, \Gamma(X_w)
\]

\[
s_c, \Gamma(X_c)
\]

\[
s_{BU}, s_{BC}, s_{RC}
\]

\[
s_A, \Gamma(X_A)
\]

\[
s_B, \Gamma(X_B)
\]

D. PER Analysis

To analyze performance of the proposed turbo network coding (TurboNC) scheme, we say that packet errors occur when in Fig. 1 the original messages from A and B cannot be both correctly decoded at D. Assume that packet error rate (PER) of a coded message with the specified length at SNR \( \gamma \) is \( P^e(\gamma) \) and packet delivery rate (PDR) is \( P(\gamma) = 1 - P^c(\gamma) \). Links \( AD, AR, BD, BR \) and \( RD \) have respectively SNR \( \gamma_{AD}, \gamma_{AR}, \gamma_{BD}, \gamma_{BR} \) and \( \gamma_{RD} \). They have PERs \( P^e_{ij} = P^e(\gamma_{ij}) \) and PDR \( P_{ij} = 1 - P^c_{ij} \). PER of the system without utilizing \( R \) is

\[
P^e_{Direct} = 1 - P^e_{AD}P^e_{BD}
\]

When the relay \( R \) forwards the XORed message, \( D \) cannot decode both message \( X_{AU} \) and \( X_{BU} \) by the DAS with network coding scheme (NetCod) suggested in [10] if it only correctly receives one or even none of the three messages from \( A, B, R \). Its PER is

\[
\beta_{NetCod} = P^e_{BD}P^e_{RD} + P^e_{AD}P^e_{BD} + P^e_{AD}P^e_{BD}P^e_{RD}
\]

When \( R \) forwards the XORed message, packet errors occur in TurboNC with the following probability

\[
\beta_{TurboNC} = 1 - P^e_{RD}P^e_{TurboNC}P(\gamma_{AD} + \gamma_{BD})
\]

\[
- (1 - P^e_{RD})P^e_{Iterate}
\]

where \( P^e_{TurboNC} \) is the probability that the TurboNC scheme correctly decodes the XORed message \( X_{RU} \) and \( P^e_{Iterate} \) is the probability that \( D \) decodes the two original messages by the iteration in Fig. 2. In Eq.(14) the addition of SNR \( \gamma_{AD} + \gamma_{BD} \) is because combining generates a signal with SNR equaling the sum of SNR of combined signals.

Let \( \alpha = P_{AR}P_{BR} \). Totally NetCod and the proposed TurboNC scheme respectively have a PER as follows

\[
P^e_i = (1 - \alpha)P^e_{Direct} + \alpha \cdot \beta_i
\]

\[
= P^e_{Direct} - \alpha \cdot (P^e_{Direct} - \beta_i)
\]

In Eq.(15) minimizing \( P^e_i \) is to maximize the second part, which is a product of two terms. The first term \( \alpha \), the probability that the relay node can be used, is common in both schemes. The second term contains the probability \( \beta_i \) (\( \beta_i \) is usually much less than \( P^e_{Direct} \)) that packet errors occur even though the relay node forwards messages. To better utilize the relay it is expected that \( \alpha \) should be as large as possible while \( \beta_i \) is as small as possible. But as \( R \) gets nearer to \( A/B, \gamma_{AR} \) and \( \gamma_{BR} \) get large and \( \alpha \) increases meanwhile \( \gamma_{RD} \) decreases which results an increase of \( \beta_i \). The conflict also occurs as \( R \) gets nearer to \( D \). It is clear that adjusting the position of \( R \)
can only satisfy either $\alpha$ or $\beta$, not both, and there is a tradeoff between the two terms in order to minimize PER.

IV. NUMERICAL EVALUATION

In this section we present the simulation results obtained by matlab. In the simulation each message has a size of 2400bits. Messages are coded by a 4-state recursive systematic convolutional code (RSC) with the code rate 1/2 and the generator matrix $(1, 5/7)$. A random permutation matrix is used in the TurboNC scheme. The received messages will be decoded respectively by different schemes: the Direct scheme without utilizing the relay node, the DAS with network coding (NetCod) [10] and the proposed scheme. Channel coding is not addressed in [10]. For the purpose of fair comparison channel coding is involved in NetCod in our simulation. In the following TurboNC-1 stands for the procedure of recovering the XORed message by the turbo decoding and recovering the original messages by maximal ratio combining. TurboNC-2 involves the iterative decoding procedure in Fig. 2.

The simulation focuses on the scenario in Fig. 1. Links experience block Rayleigh fading. $A$ and $B$ are close to each other. The positions of $A/B$ and $D$ are fixed unless otherwise specified. $R$ lies between $A/B$ and $D$ and has an adjustable distance $d_{R-AB}$ to $A/B$.

We first demonstrate how the position of the relay node affects the system performance. Average SNR of links $AD/BD$ is fixed at 5dB. Adjusting the position of $R$ between $A/B$ and $D$ changes the normalized distance $d_{R-AB}/d_{AD}$. Average SNR of links $AR$, $BR$ and $RD$ can be calculated from the normalized distance $d_{R-AB}/d_{AD}$ according to two-ray model with the path loss exponent (equalling 4 in the simulation). Fig. 6 shows the PER under different distance. In all schemes PER reaches the minimum when $R$ lies to the left of the middle point. In TurboNC scheme when the messages are successfully transferred over links $AR/BR$, the turbo decoding and combining diversity can reduce the message errors over the multi-access channel from $A/B/R$ to $D$. Moving the relay node further leftward can improve $P_{AR}P_{BR}$ and reduces the total PER. As a result the minimum PER of TurboNC is much less than that of NetCod. When the relay is not very close to $A/B$, the turbo decoding can decode the XORed message with a high enough probability and leave little room for iterative decoding. As $R$ gets nearer to $A/B$ and farther away from $D$, the probability that $D$ correctly decodes the XORed message increases and the iterative decoding in Fig. 2 helps reduce the total PER.

In the following we consider two typical scenarios. In the first scenario $A$ and $B$ are near to each other and $R$ lies exactly in the middle of $A/B$ and $D$ and only serves as a relay node. In the second scenario $A$, $B$ and $R$ are near to each other and $AR/BR$ has an average SNR of 40dB. In this scenario all nodes can mutually cooperate and each node can help the other two. Figs. 7-8 show PER under the two scenarios respectively. In either scenario PER decreases as SNR of the direct link $AD/BD$ increases.

In the first scenario links between $R$ and other nodes $A, B, D$ have an average SNR 12dB higher than the direct links $AD/BD$. With a high probability $R$ can forward and $D$ can decode the XORed message by turbo decoding. Then $D$ can decode the rest messages by applying combining diversity according to Eq.(9). When $R$ forwarded but $D$ failed to decode the XORed message, the estimated signal by LLR algebra in Eq.(5) has a lower SNR than the original signal. Therefore the iterative decoding contributes little and TurboNC-1 and TurboNC-2 have similar performance, both of which provide about 1dB gain to NetCod.

In the second scenario three links $AD$, $BD$ and $RD$ have the same average SNR. In the case where $D$ cannot recover the XORed message, the iterative decoding can still salvage
some messages if instantaneous SNR of three links is not too weak. As a result the gap between TurboNC-1 and TurboNC-2 becomes obvious. TurboNC-1 provides a gain up to 1.8 dB to NetCod.

Let the transmission time of an original message be $T$. Then with coding rate equalling $1/2$ the transmission of a message after channel coding takes $2T$ time. Table I summarizes the time required for the transmission of two messages from $A/B$ to $D$ in different schemes. TurboNC only takes $5T$ time to transmit two messages. It is more efficient than NetCod which takes $6T$ time. To reflect the potential retransmissions in times of failure, Fig. 9 shows the expected transmission time (ETT) corresponding to the second scenario, where ETT is defined as the ratio of transmission time in Table I to $(1-\text{PER})$ with PER in Fig. 8. It is clear that TurboNC always has very obvious superiority over NetCod and the merit of iterative decoding is at low SNR.

V. CONCLUSION AND FUTURE WORK

We discussed network coding-based relay model and focused on two key aspects: channel efficiency and reliability. The proposed turbo network coding scheme and its decoding method can solve the two problems together. It improves channel efficiency by letting the relay node transmit only parity check bits of the XORed message. It is also effective in salvaging messages from erroneous signals by joint channel and network decoding (turbo decoding, iterative decoding and signal combining). Compared with the existing schemes, the proposed scheme can provide about 1.8 dB gain in the case of mutual cooperation among mobile nodes. In the future we will design practical protocols to implement the proposed relay scheme.

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