# DETERMINISTIC STRUCTURED NETWORK CODING FOR WWAN VIDEO BROADCAST WITH COOPERATIVE PEER-TO-PEER REPAIR

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## ABSTRACT

Recent research has exploited the multi-homing property (one terminal with multiple network interfaces) of modern devices to improve communication performance in wireless networks. Cooperative Peer-to-peer Repair (CPR) is one example where given simultaneous connections to both a Wireless Wide Area Network (WWAN) and an ad-hoc Wireless Local Area Network (WLAN), peers receiving different subsets of WWAN broadcast packets can exchange received WWAN packets with their ad-hoc WLAN peers for local recovery. In our previous work, we have shown that by using Network Coding (NC) to linearly combine received packets into new CPR packets for local exchanges, packet recovery can be improved. Moreover, by imposing Structure on Network Coding (SNC) when encoding a CPR packet, decoding of at least the important packets becomes possible in the event when insufficient number of CPR packets were received for full recovery.

Given SNC is used during CPR, the key decision for each peer is to determine which SNC type to encode a repair packet at each WLAN transmission opportunity. The decision is further complicated by the observation that peers in general receive different numbers of CPR packets from neighbors due to varying amount of WLAN link contentions and interference experienced. In this paper, we propose a novel counter-based deterministic SNC type selection scheme. Using this approach, we show that a simple local optimization procedure, taking advantage of available neighbors' state information, can be easily implemented to further improved CPR performance. Simulation results show that our proposed scheme outperformed our previous randomized SNC type selection scheme by up to 1.87dB.

***Index Terms***— WWAN video broadcast, cooperative peer-to-peer repair, structured network coding

## 1. INTRODUCTION

It is now common for wireless devices to be equipped with multiple network interfaces, capable of connecting simultaneously to Wireless Wide Area Network (WWAN) and Wireless Local Area Network (WLAN). Exploiting this multi-homed property, recent research on cooperative ad-hoc groups [1, 2] has showed that new transmission paradigms can be constructed. [1] showed that aggregation of an ad-hoc group's WWAN bandwidths can speed up individual peers' infrequent but bursty large content downloads. [2] showed that smart striping of FEC-protected (Forward Error Correction) time-sensitive media packets across WWAN links can alleviate single-channel burst losses, while avoiding interleaving delay experienced in a typical single-channel FEC interleaver.

Another paradigm exploiting local users' multi-homed capability is Cooperative Peer-to-peer Repair (CPR) [3], where multi-homed peers, listening to the same WWAN video broadcast and connected to each other via ad-hoc WLAN, can exchange received WWAN packets locally via WLAN to repair WWAN losses. Instead of exchanging original received WWAN packets, we have shown that by linearly combining received packets into a CPR packet for exchange using network coding (NC) [4], repair performance can be improved. Furthermore, by imposing structure on network coding (SNC) when encoding a CPR packet, decoding of at least the important packets becomes possible in the event when insufficient number of NC packets were received for full recovery [3]. Experiments showed that peers with SNC can achieve up to 14dB gain in video quality over peers without CPR, and up to 5dB gain over peers with NC and CPR but SNC is not used.

In a CPR network where SNC is enabled, the crucial decision for a peer is which SNC type—each corresponding to a particular subset of video frames in a Group of Picture (GOP)—should a CPR packet be encoded in, when given a local WLAN transmission opportunity. In our previous work [3], a simple *randomized* approach was employed where peers decide the SNC type randomly based on globally pre-determined weights assigned to each SNC type. While this approach is effective in enforcing *globally* the desired proportions of SNC types as dictated by the pre-determined weights, it does not *locally* distribute CPR packets in a sensible order; i.e., packets of more important SNC types are transmitted first before less important ones. This is of particular importance when the number of received CPR packets per peer varies largely due to different amount of WLAN transmission contention and interference experienced. In such case, poor peers receiving few CPR packets should receive large portions of SNC packets of more important types, not the globally weighted distribution of SNC types as other peers.

In this work, we propose a novel *counter-based deterministic* SNC packet selection scheme with local optimization for CPR network. Our deterministic selection scheme ensures the important SNC types are always transmitted before less important ones in a local region. Moreover, by imposing a deterministic order when selecting SNC types, it is amenable to simple local optimizations that exploit exchanged neighbor state information for further gain. In particular, our contributions are as follows:

1. We first propose to divide CPR peers into sub-classes to accurately capture variance in CPR packet recovery capabilities.
2. We then propose a counter-based deterministic SNC selection scheme for each peer to select SNC types at WLAN transmission opportunities.
3. We propose a local optimization procedure, given the counter-based deterministic SNC selection scheme, that utilizes limited (and possibly stale) available neighbor state information to make more locally optimal SNC selections.
4. We derive accurate formulas to track the performance of our proposed SNC selection scheme.

Simulation results showed that using our deterministic approach, CPR sub-classes and local optimization, we achieved up to 1.87dB gain over our previously proposed randomized scheme.

Our paper is organized as follows. Section 2 describes the video source and network models and overviews our previously proposed SNC. We then present our CPR optimization framework and discuss in detail our proposals on CPR sub-classes, deterministic SNC selection and local optimization in Section 3. We report simulation studies in Section 4 and conclude in Section 5.

## 2. VIDEO MULTICAST SYSTEM AND COOPERATIVE PEER-TO-PEER REPAIR

In this section, we discuss our chosen video source and network model, and overview our previously proposed Structured Network Coding (SNC) for CPR.

### 2.1. Video Source Model & Assumptions

We use H.264 codec for video encoding. A H.264 video stream is a series of GOPs, each containing an I-frame and $M-1$ P-frames. Each P-frame $F_i$ uses its previous frame $F_{i-1}$ for motion compensation. A GOP forms a dependency chain. A frame $F_i$ is correctly decoded if it is correctly received, and the frame it referenced, $F_{i-1}$, is correctly decoded. Each video frame $F_i$ is encoded from original picture $F_i^o$ with source coding rate $r_s^i$. $r_s^i$ is subsequently divided into $R_s^i = \left\lceil \frac{r_s^i}{S_{pkt}} \right\rceil$ packets, $\mathcal{P}_i = \{p_{i,1}, p_{i,2}, ..., p_{i,R_s^i}\}$, for transmission, where $S_{pkt}$ is the packet size. If $F_i$ is correctly decoded, the resulting *distortion reduction* is $d_i$.

### 2.2. Network Model & Assumptions

We assume that a group or *collective* of $N$ peers are listening to the same WWAN video broadcast, and are locally connected in an ad-hoc WLAN network where WLAN broadcast mode is enabled (each WLAN transmission can be received by multiple neighboring peers within range). After the media source transmits a GOP of $M$ frames via WWAN to the CPR collective in time duration $T$ (one *epoch*), peers perform CPR; i.e, they exchange NC-encoded CPR packets via WLAN broadcast to repair this GOP in time $T$ during WWAN transmission of the next GOP. The initial playback buffer delay is thus $2T$.

We assume peers listening to the same WWAN broadcast channel experience independent and identically-distributed (iid) losses from WWAN base station, resulting in different subsets of received WWAN packets. For WLAN, though raw transmission rate is relatively large, peers need to contend for the shared medium. In this work, we rely on the underlying 802.11 MAC layer scheduling protocol to resolve potential contention; we assume that MAC layer will prompt the application layer when a transmission opportunity is available. Note the MAC-controlled scheduling is completely distributed for all the peers. We assume that peer $n$ receives a random variable number $R_n$ of CPR packets in time $T$, and the mean of $R_n$ is $R$. The main question at the application layer is: what CPR packet should peer $n$ send to its neighbors when given a transmission opportunity? This is discussed in Sections 3.3 and 3.4.

### 2.3. Structured Network Coding

We now overview our previously proposed SNC [3]. Given $M$ frames in a GOP, $\mathcal{F} = \{F_1, \ldots, F_M\}$, we first denote $\mathcal{P}^*$ as the set of *native packets* in the GOP, i.e., $\mathcal{P}^* = \{\mathcal{P}_1, \ldots, \mathcal{P}_M\}$. Rather than using raw received packets from source, we have shown [3] that NC-encoding a CPR packet, $q_n$, as a randomized linear combination of raw received native packets $\mathcal{G}_n$ from source and CPR packets $\mathcal{Q}_n$ from neighbors, can improve packet recovery performance:

$$q_n = \sum_{p_{i,j} \in \mathcal{G}_n} a_{i,j} p_{i,j} + \sum_{q_m \in \mathcal{Q}_n} b_m q_m \quad (1)$$

where $a_{i,j}$'s and $b_m$'s are coefficients for the received native and CPR packets, respectively. We call this approach *Unstructured Network Coding* (UNC). The advantage of UNC is that *any* set of $|\mathcal{P}^*|$ received *innovative*[1] packets can lead to full recovery of all packets in the GOP. The shortcoming of UNC is that if a peer receives fewer than $|\mathcal{P}^*|$ innovative packets, then this peer cannot recover *any* native packets using the received CPR packets.

To address UNC's shortcoming, we impose structure in the coefficients $a_{i,j}$'s and $b_m$'s in (1) when encoding a CPR packet, so that partial recovery of important frames in the GOP at a peer when fewer than $|\mathcal{P}^*|$ innovative packets are received is possible. Specifically, we define $X$ *SNC groups*, $\Theta_1, \ldots, \Theta_X$, where each $\Theta_x$ covers a different subset of frames in the GOP and $\Theta_1 \subset \ldots \subset \Theta_X = \mathcal{F}$. $\Theta_1$ is the most important SNC group, followed by $\Theta_2$, etc. Corresponding to each SNC group $\Theta_x$ is a *SNC packet type* $x$. Further, let $g(j)$ be index of the smallest SNC group that includes frame $F_j$. As an example, in Fig.1 frame $F_1, F_2$ are in SNC group $\Theta_1$ and $F_1, \ldots, F_4$ are in SNC group $\Theta_2$. The smallest SNC group that includes $F_3, F_4$ is $\Theta_2$ with index $2 = g(3) = g(4)$.

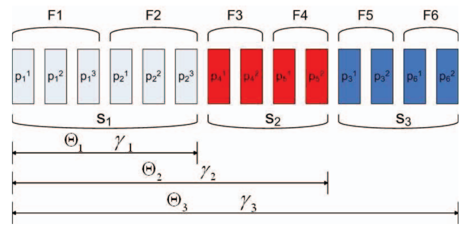



**Fig. 1**. Example SNC structures $\Theta_x$ and transmission weights $\gamma_x$.

A CPR packet $q_n(x)$ of type $x$ can now be generated as follows:

$$q_n(x) = \sum_{p_{i,j} \in \mathcal{G}_n} U(g(i) \leq x)\, a_{i,j} p_{i,j} + \sum_{q_m \in \mathcal{Q}_n} U(\Phi(q_m) \leq x)\, b_m q_m \quad (2)$$

where $\Phi(q_m)$ returns the SNC type of packet $q_m$, and $U(\mathtt{c})$ evaluates to 1 if clause $\mathtt{c}$ is true, and 0 otherwise. In words, (2) states that a CPR packet $q_n(x)$ of type $x$ is a random linear combination of received native packets of frames in SNC group $\Theta_x$ and received CPR packets of type $\leq x$. Using (2) to generate CPR packets, a peer can now recover frames in SNC group $\Theta_x$ when $|\Theta_x| < |\mathcal{P}^*|$ innovative packets have been received.

## 3. COUNTER-BASED DETERMINISTIC SNC SELECTION FOR CPR OPTIMIZATION

In this section, we first introduce our CPR optimization framework: our chosen objective function and how SNC structures are optimized. We then present in detail our proposed optimization techniques: i) CPR sub-class modeling that captures variance in peers' CPR capability, ii) counter-based deterministic SNC type selection scheme, and iii) local optimization enabled by our deterministic SNC selection scheme. Formulas that accurately capture the performance of our proposed scheme are derived at the end of this section.

### 3.1. CPR Optimization Framework

CPR optimization framework determines the globally optimal SNC structure that minimizes the visual distortion for a given CPR collective. We first define *segment* $s_x$ as the set of frames in SNC group $\Theta_x$ but not $\Theta_{x-1}$; for example $s_2$ in Fig. 1 has frames $F_3, F_4$. We can now write the expected distortion of a GOP for a peer in a CPR collective, given $X$ SNC groups $\Theta_x$'s, as:

$$D = D_{init} - \sum_{x=1}^{X} \left( \sum_{F_j \in s_x} d_j(r_s^j, r_s^{j-1}) \right) \alpha(s_x), \quad (3)$$

where $D_{init}$ is the distortion if no packets are received at a peer, $d_i(r_s^i, r_s^{i-1})$ is the distortion reduction for $F_i$ given $F_i$ and previous frame $F_{i-1}$ are encoded with rates $r_s^i$ and $r_s^{i-1}$ respectively, and $\alpha(s_x)$ is the recovery probability of segment $s_x$ after CPR is performed. $\sum_{F_j \in s_x} d_j(r_s^j, r_s^{j-1})$ is the distortion reduction for segment $s_x$.

$\alpha(s_x)$ depends on both WWAN packet loss statistics and *CPR recovery probability* $Q(\Omega, x)$, the probability that CPR recovers $\Omega$ known WWAN lost packets in SNC group $\Theta_x$. To impart intuition, first suppose there is only one SNC group with $R_s$ packets. $\alpha(s_1)$ can then be written simply as $1 - p_{grp}(R_s)$, where $p_{grp}(R_s)$ is the *group loss probability* that there were non-zero packet losses in

[1] A new packet is innovative for a peer if it cannot be written as a linear combination of previously received packets by the peer.

WWAN broadcast to a peer, *and* CPR cannot recover all those losses at the peer. Given iid WWAN losses, $p_{grp}(R_s)$ can be written as[2]:

$$p_{grp}(R_s) = \sum_{i=1}^{R_s} \binom{R_s}{i} l_{avg}^i (1 - l_{avg})^{R_s - i} \times [1 - Q(i, 1)] \qquad (4)$$

where $l_{avg}$ is the average WWAN loss rate and $Q(i, 1)$ is the probability that CPR recovers $i$ known WWAN lost packets in SNC group $\Theta_1$. Since there is only one SNC group, $Q(i, 1) = 1$ when $R \geq i$; and 0 otherwise.

In general, there are $X$ SNC groups, and we define $\gamma_x$ as the *transmission weight* associated with SNC group $\Theta_x$; i.e., given $R$ expected number of CPR packets received by an average peer, the expected number of CPR packets of type $x$ is $R\gamma_x$. In Fig. 1, the three SNC groups have weights $\gamma_1, \gamma_2$ and $\gamma_3$, and $\sum_{x=1}^{3} \gamma_x = 1$.

CPR recovery probability $Q(\Omega, x)$ depends on how SNC type selection is performed at each peer to achieve desired proportions $\gamma_x$'s; in Section 3.5, we derive $Q(\Omega, x)$ formally for our proposed counter-based deterministic SNC selection scheme (to be discussed in Section 3.3). $\alpha(s_x)$'s for $X$ SNC groups can be derived from the single SNC group case using Eq. (4) as the basis for $\Theta_1$ and recursively considering larger groups $\Theta_x$, $x \geq 2$. We omit derivations for $\alpha(s_x)$'s and refer readers to [5] for details.

With Eq. (3), our objective is to minimize the expected distortion by finding the optimal SNC groups $\Theta_x$'s and their associated weights $\gamma_x$'s as follows:

$$\min_{\Theta_x, \gamma_x} D \qquad (5)$$

Note that SNC groups $\Theta_x$'s and their associated weights $\gamma_x$'s are both defined in a *global* sense; i.e., one set of SNC groups and weights for all peers in the collective. In practice, we observe non-negligible variance in the number of CPR packets received by a peer, and simply applying $\Theta_x$'s and $\gamma_x$'s to every peer would lead to very poor performance for peers with very few received CPR packets. This motivates us to propose the three optimization techniques described below.

### 3.2. CPR Sub-Classes

To capture variance in $R_n$, we observed through simulations that $R_n$ follows a Gaussian distribution with mean $R$ and variance $\sigma^2$. Given a Gaussian model, we propose to divide one CPR collective into three equal-sized sub-classes with $R^-$, $R$ and $R^+$ average number of CPR packets, where $R^-$ represents the *poor peers* who receive fewer CPR packets than average peers and $R^+$ represents the *rich peers* who receive more CPR packets. The three sub-class divisions properly account for both poor and rich peers, while keeping a representative middle class with average CPR capability and small intra-class variance. Simulations show that using more sub-classes reaped marginal improvement compared to the three sub-classes divisions, while the increase in computation complexity due to more sub-classes is significant.

Given $R_n$ is Gaussian-distributed and the three CPR sub-classes are of equal size, one can locate the boundaries of the three sub-classes as $R_n^- \approx R - \frac{3\sqrt{2}}{10}\sigma$ and $R_n^- \approx R + \frac{3\sqrt{2}}{10}\sigma$. We can then calculate the mean of the three sub-classes as $R^- \approx R - \sigma$ and $R^+ \approx R + \sigma$. With the CPR sub-class concept, expected distortion for each sub-class can be obtained via Eq. (3), and total distortion $D$ is simply the sum of three sub-classes's distortions.

Note that although we divide one CPR collective into three sub-classes with three different mean values, the division is performed in a statistical sense, and one cannot determine *a priori* exactly which peer is in which CPR sub-class. Hence one set of SNC groups $\Theta_x$'s and associated weights $\gamma_x$'s returned in Eq. (5) is applied to all peers in the CPR collective, and the variance in $R_n$ is only captured statistically by the optimization process. In the following, we show further local optimization can be performed by carefully selecting proper SNC types for transmission in a local region.

### 3.3. Counter-based Deterministic SNC Selection

In Eq. (5), the optimization returns SNC structures $\Theta_x$ and associated weights $\gamma_x$'s without designating an implementation. We first discuss how $\gamma_x$'s can be implemented such that CPR packets corresponding to important SNC groups are always transmitted before packets of less important groups.

In our previous work [3], we proposed a *randomized* scheme where a peer randomly selects a SNC type according to global weights $\gamma_x$'s. While it enforces the desired packet proportions in SNC groups, it does not conform to a logical order where small (hence more important) SNC types are transmitted first. When there is non-negligible variance in $R_n$, a logical transmission order ensures that poor peers receiving few CPR packets would get important packets in larger proportions than indicated by the global weights $\gamma_x$'s, ensuring a minimum satisfactory level of quality.

To impose a logical order, we propose a *counter-based deterministic* SNC selection scheme for peer $n$ to select the SNC type $x$. Each peer keeps track of the number of received CPR packets thus far and we denote it as $R^o$. When a transmission opportunity arises for a peer, he transmits SNC type 1 if $R^o \leq R\gamma_1$. A peer transmits SNC type 2 when $R^o > R\gamma_1$ and $R^o \leq R(\gamma_1 + \gamma_2)$, and so on. When $R^o > R$, peer $n$ selects SNC type based on a timer instead; i.e., if the current time is in-between $T\sum_{i=1}^{j-1} \gamma_i$ and $T\sum_{i=1}^{j} \gamma_i$, then the chosen SNC type is $j$. Using this method, one can enforce proportions $\gamma_x$ globally and yet maintain a logical order.

Note we use *reception* counter instead of *transmission* counter to maintain the logical order. The reason is twofold. First, using WLAN broadcast mode, the number of packets received by a collective can far exceed the number of packets transmitted (each transmitted packet is received by multiple listening peers). Hence using transmission counter would mean too many packets of small types if the number of packets transmitted per peer is small. Second, a transmitted packet may not be correctly received in time by neighbors due to in-air collision and interference. Hence reception counter provides a more accurate estimate of neighbors' current states.

Because of deterministic transmissions, packets of small SNC types are always transmitted earlier than packets of large SNC types. This property has three implications: 1) Peers receive packets of more important SNC types earlier than less important SNC types; 2) If $R_n$ is smaller than $R$, then $n$'s neighbors receive more packets of more important SNC types than indicated by $\gamma_x$'s, which benefits peer $n$'s poor neighbors; and 3) Peers can perform simple local optimization based on the neighbor state information to further optimize local SNC type selection, as will be discussed in Section 3.4.

### 3.4. Local Optimization given Deterministic SNC Selection

During CPR exchange, a peer can learn of their immediate neighbors' (possibly stale) state information, if state information is piggybacked on top of each exchanged CPR packet. Armed with neighbors' state information, a peer can now choose a smaller SNC type, if the peer deduces that his neighbors have not fully recovered that SNC type. Doing so means more important SNC types are more likely to be recovered before peers can proceed to select larger SNC types. Note that this simple local optimization is not possible with a randomized SNC selection approach, where at any given time it

[2]We assume each native packet has been successfully delivered from source via WWAN to at least one peer in a large collective, so that CPR can attempt recovery of that packet to other peers locally via WLAN. See [5] for more general settings when this assumption may not be true.

is more difficult to deduce the appropriate SNC type to transmit to a peer's neighbors. Moreover, compared to the more complex RD-based local optimization [3] for the randomized approach, our simple local optimization requires very small computation overhead.

Based on the discussion above, we piggyback *SNC group recovery status* on top of each CPR packet. The status information reveals how many packets the transmitting peer has for each SNC group. Since there are at most $M$ SNC types, and generally $M$ is not a large number (15 in our setup), this exchanged status information requires minimum bit overhead. Based on the status information, peer $n$ does the following: 1) Before deciding which SNC type to encode, peer $n$ first checks whether its neighbors have recovered the previous SNC group. If not, peer $n$ continues to transmit packets of the previous SNC type; 2) After making a decision on SNC type, peer $n$ checks whether its neighbors have recovered the decided SNC group. If so, $n$ moves on to check the next SNC type.

When peer $n$ checks whether its neighbors have recovered SNC group $\Theta_x$, for each neighbor $m$, peer $n$ first calculates the time difference $\tau$ between the current time and the timestamp when the neighbor information was received. The expected number of packets $m$ can receive during $\tau$ is $\frac{\tau R}{T}$. If the expected number of received packets is greater than the number of packets neighbor $m$ needs to recover SNC group $\Theta_x$, then $m$ is assumed to have recovered $\Theta_x$; otherwise peer $n$ assumes that $m$ still needs packets of type $x$.

### 3.5. CPR Packet Recovery Capability

In this section, we derive $Q(\Omega, x)$ given our proposed counter-based deterministic SNC selection scheme. In particular, we derive recursions that count the number of WWAN *packet loss patterns*, given $\Theta_x$'s and $\gamma_x$'s.

Suppose $\Omega$ WWAN packets are lost in SNC group $x$. The probability that CPR can help recover these lost packets is written as:

$$Q(\Omega, x) = \frac{LP_R(s_1, s_x, \Omega)}{LP_A(s_1, s_x, \Omega)} \tag{6}$$

where $LP_A(s_1, s_x, \Omega)$ is the total number of *all* possible packet loss patterns in segments $s_1$ to $s_x$ in SNC group $\Theta_x$. $LP_R(s_1, s_x, \Omega)$ is the number of packet loss patterns that are CPR *recoverable* within the segment range. The ratio of the two is $Q(\Omega, x)$.

$LP_A(s_1, s_x, \Omega)$ can be recursively obtained with $LP_A(s_m, s_x, \omega)$, the number of loss patterns starting from $s_m$ to $s_x$ with $\omega$ losses.

$$LP_A(s_m, s_x, \omega) = \begin{cases} \sum_{i=lo}^{hi} LP_A(s_{m+1}, s_x, \omega - i) & m < x \\ 1, & \text{otherwise} \end{cases} \tag{7}$$

$lo$ and $hi$ are the minimum and maximum number of lost packets that can be in segment $s_m$:

$$lo = \max\{0, \omega - \sum_{j=m+1}^{x} \sum_{k \in s_j} R_s^k\}, \qquad hi = \min\{\omega, \sum_{k \in s_m} R_s^k\} \tag{8}$$

$LP_R(s_1, s_x, \Omega)$ can be similarly written as in Eq.(7). $lo$ and $hi$ for $LP_R(s_1, s_x, \Omega)$ are updated to reflect the number of recoverable packets by replacing $\sum_{k \in s_m} R_s^k$ in Eq.(8) with $N_m$, the number of possible *recoverable* packets in segment $s_m$:

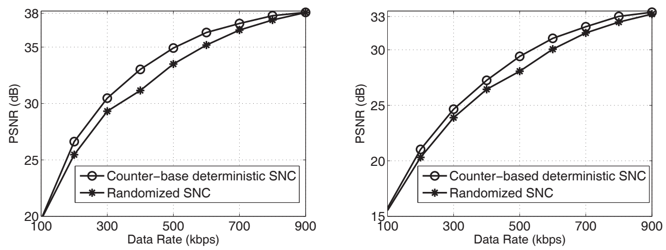
$$N_m = \begin{cases} \sum_{k \in s_m} R_s^k, & R \sum_{j=m}^{x} \gamma_j \geq \Omega \\ \min\left\{ \sum_{k \in s_m} R_s^k, \quad \lfloor R\gamma_m \rfloor \right\}, & \text{otherwise} \end{cases} \tag{9}$$

The first line in Eq. (9) is due to the definition of SNC groups that CPR packets of a larger SNC group can help with previous SNC groups. As long as $R \sum_{j=m}^{x} \gamma_j \geq \Omega$, *any* number of the $\Omega$ lost packets can fall in segment $s_m$, and they can be recovered. When the condition is not met, it implies that SNC group $m$ cannot use help from later SNC groups and might not be able to hold all the $\Omega$ lost packets. Note the above analysis assumes the sub-class with average $R$ CPR packets in Eq. (9). It is valid for the other two sub-classes by substituting $R$ with $R^-$ and $R^+$ respectively.

## 4. EXPERIMENTATION

Two test video sequences `news` and `foreman` were used for simulations at CIF resolution ($352 \times 288$). The GOP size was chosen at 15 frames: one I-frame followed by 14 P-frames.

We performed simulations using QualNet. The underlying CPR scheduling was 802.11 MAC with broadcast enabled. We set up a CPR network by uniformly placing 50 peers in a $1000 \times 1000m^2$ area and the WLAN transmission range was set to 280m. Given one GOP was 15 frames and video was encoded at 15fps, $T$ was 1s.




a) `news` b) `foreman`

**Fig. 2**. Counter-based deterministic SNC selection with local optimization versus randomized approach.

Fig. 2 compared our proposed counter-based deterministic SNC packet selection approach with local optimization, to the randomized approach. Fig. 2a used the `news` sequence. Because of our deterministic approach that guarantees packet reception of small but important SNC types, and because of the local optimization and CPR sub-classes that handle the inadequacy of pure distributed transmissions for peers with different CPR capabilities, our proposal greatly outperformed the traditional randomized scheme. At its maximum, our proposed scheme achieved 1.87dB gain over the randomized approach. Fig. 2b showed similar results for the `foreman` sequence. The deterministic scheme obtained 1.34dB gain over the randomized SNC selection scheme in this case.

## 5. CONCLUSION

In this paper, we propose a counter-based deterministic SNC selection scheme for peers to select NC types for CPR exchanges of repair packets to collectively alleviate WWAN video broadcast losses. Combining CPR sub-classes and local optimization, we show through simulations that our proposed scheme can improve WWAN broadcast video quality by up to 1.87dB over a previous randomized SNC selection scheme.

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