Network Coding Based Cooperative Peer-to-Peer Repair in Wireless Ad-Hoc Networks

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Outline

- Introduction
- Several CPR protocols
- Evaluation
- Conclusion

Introduction

- MBMS for 3G cellular networks employ broadcast/multicast transport to serve rich multimedia content to large users simultaneously
  - Main objective is to ensure error-free content delivery
  - May use FEC to repair or retransmission

Introduction

- Losses among MBMS subscribers are often uncorrelated. Therefore, a node can procure lost packets from others which have those packets

CPR(1)

- CPR- Cooperative peer-to-peer repair scheme
  - Which leverages IEEE 802.11 peer-to-peer connections to achieve repair of 3G broadcasting losses
- Suppose a batch of packets K is delivered via MBMS, $K=\{p_1, p_2, p_3, \dots, p_k\}$
- Due to transmission errors, some node n_i may receive a subset $R_i \subseteq K$ of packets

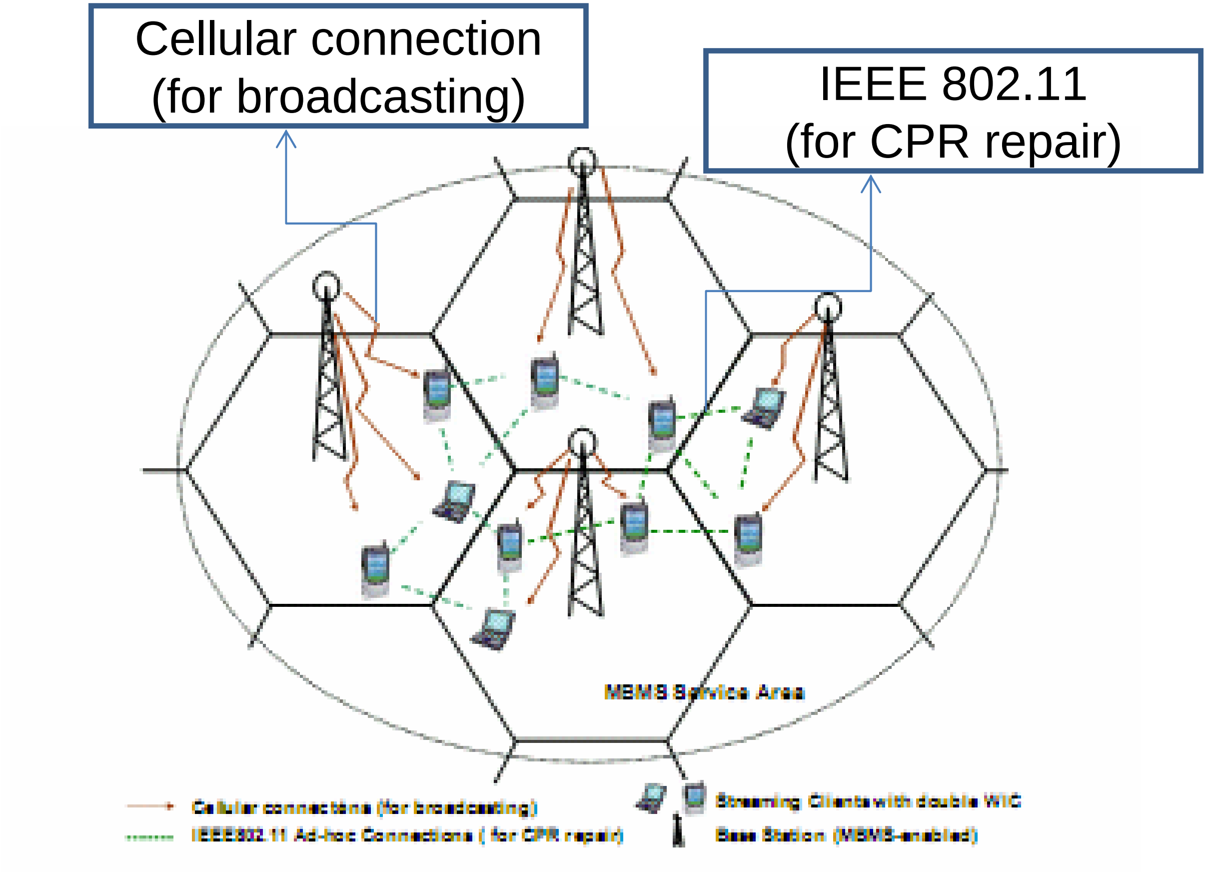
CPR(2)

- The main goal is to find a repair schedule so that each node has all the packets in K
- Using a K*N matrix BMM to record the availability of packet p_k on each node
  - BMM^w: the updated BMM after w transmissions
- Let N*1 matrix t_w be the transmission policy at the w^{th} transmission round
  - $t_{wi} = k$ if n_i is selected to send packet k

CPR(3)

- The solution to this CPR problem is a series of transmission policies $T_Q = (t_1, t_2, \ldots, t_Q)$, which can accomplish the transition $BMM^0 \Rightarrow BMM^1 \Rightarrow \ldots \Rightarrow BMM^Q = BMM^E$,where the all elements of BMM^E are 1
  - These transmission policies are produced by some metrics

CPR in 3G Network



NC-CPR

- Network coding based CPR
- Since the minimum latency problem for NC-CPR is NP-Hard, a heuristic-based NC-CCPR is proposed

NC-CCPR(1)

- Centralized NC-CPR
- Assume all the nodes have exact one-hop and two-hop neighbors information
- Using 4 metrics

NC-CCPR(2)

- C1: a node with more pkts should have higher chance to transmit
- C2: the fewer pkts a node’s neighbors have, the higher chance the node should transmit
- C3: the more neighbors a node has, the higher chance it should transmit
- C4: the fewer two-hop neighbors a node has, the higher chance it should transmit

$$
\begin{aligned}
Rank &= Index_{\mathcal{T}^t}(\max\{C_1 * \overrightarrow{V}_{EP} - C_2 * \overrightarrow{V}_{NP} \\
&+ C_3 * \overrightarrow{V}_{N} - C_4 * \overrightarrow{V}_{THN}\}), \qquad (1)
\end{aligned}
$$

Algorithm 1: NC-CCPR Transmission Policy

Input : $G = (\mathcal{N}, \mathcal{L}_{\mathcal{T}}, \mathcal{L}_{\mathcal{I}}),\ \overrightarrow{h}^{t-1}$

Output: $\overrightarrow{h}^{t}$

Transmit node set at round t → $\mathcal{T}^t \leftarrow \mathcal{N} \setminus \{\forall n_i \in \mathcal{N} | h^{t-1}(i) = 1\}$;

$\overrightarrow{h}^{t} \leftarrow \overrightarrow{\emptyset}_{N\times 1}$;

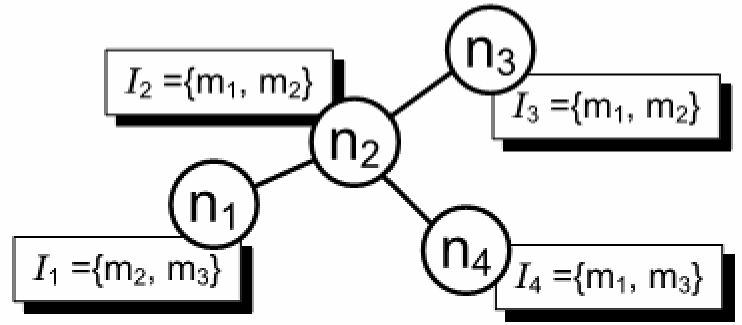
while $\mathcal{T}^t \neq \emptyset$ **do**

- $n_k \leftarrow \mathcal{T}^t(Rank(\mathcal{T}^t))$;
- $neighborSet \leftarrow \forall n_i \in \mathcal{T}^t | (n_i, n_k) \in \mathcal{L}_{\mathcal{T}}$;
- $\mathcal{T}^t \leftarrow \mathcal{T}^t \setminus (neighborSet \cup \{n_k\})$;
- $twoHopSet \leftarrow$ $\forall n_i \in \mathcal{T}^t | \forall n_j \in neighborSet, (n_i, n_j) \in (\mathcal{L}_{\mathcal{T}} \cup L_I)$;
- $\mathcal{T}^t \leftarrow \mathcal{T}^t \setminus twoHopSet$;
- $\overrightarrow{h}^{t}(k) \leftarrow 1$;

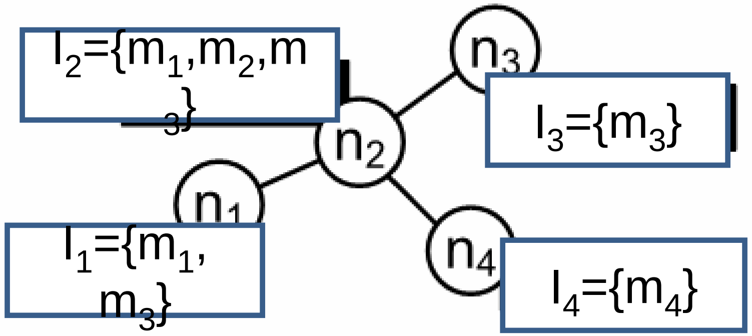
end

$return\ \overrightarrow{h}^{t}$;

- Objective: All nodes have all the packets
  - $\{m_1, m_2, m_3\}$



	CPR	NC-CPR
1	n_1: m_3	n_1: m_3
2	n_2: m_1	n_2: $m_1 \oplus m_2 \oplus m_3$ *repair complete*
3	n_2: m_2	
4	n_2: m_3 *repair complete*	



CPR	NC-CCPR	best
N2:m1	N2:m1m2m	N4:m4
N2:m2	N4:m4	N2:m1m2m3m4
N2:m3	N2:m4	
N4:m4		
N2:m4		

NC-DCPR(1)

- Distributed NC-CPR
- In practice, it is difficult for each node to get global information
- The header of packet should contain the encoding vector and the number of innovative packets the transmitting nodes have
  - The receiving nodes can then estimate the total number of neighbors' packets

NC-DCPR(2)

$$TWI = TP + RWI + SOWI + NOWI, \qquad (2)$$

$$SOWI = \frac{C_1 \times M}{\#ExistingPackets} \qquad NOWI = \frac{C_2 \times (\#Neighbors' Packets)}{\#Neighbors \times M}$$

- TP(Transmit Penalty) and RWI(Random Wait Interval) are used to reduce the chance that a highly ranked node transmits all the time

Simulation

- $1000*1000m^2$ square network
- 3G MBMS sends at 384kbps
- $epoch = \frac{8 \times B \times M}{384} ms$ B: packet size in bytes
- M: Batch size
- IID: loss rate L
- STL: nodes within $\frac{1000}{\sqrt{2}} \times \frac{1000}{\sqrt{2}} m^2$ square have 0.75L
- outside have 1.25L
- [C1, C2, TP, max RWI] = [1, 2, 4, 0.5]

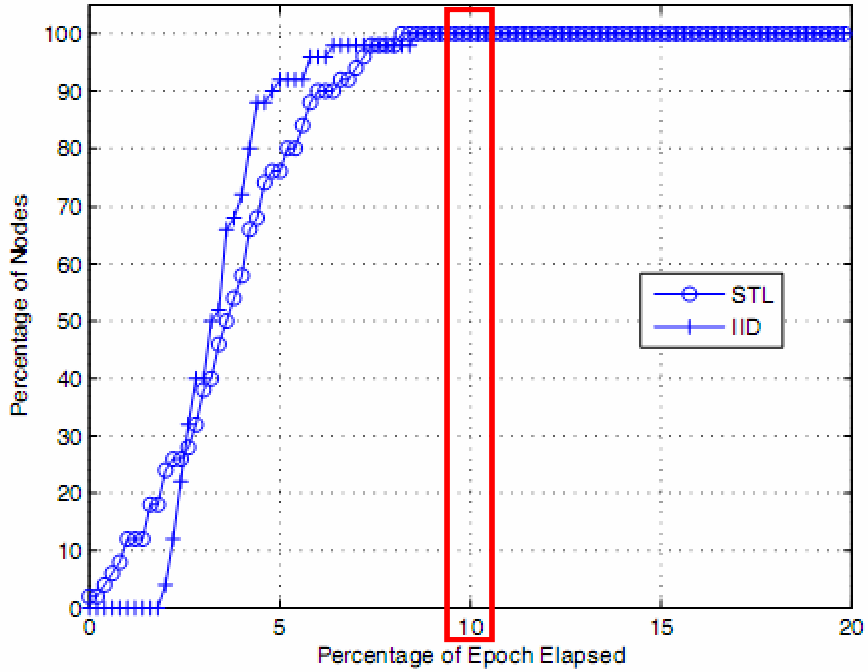


Fig. 3. CDF of NC-DCPR protocol repair time. Comparison between loss models STL and IID. MBMS loss rate is 0.3. Batch size is 100 and packet size is $1000 bytes$.

CPR without NC needs around 40% of the epoch

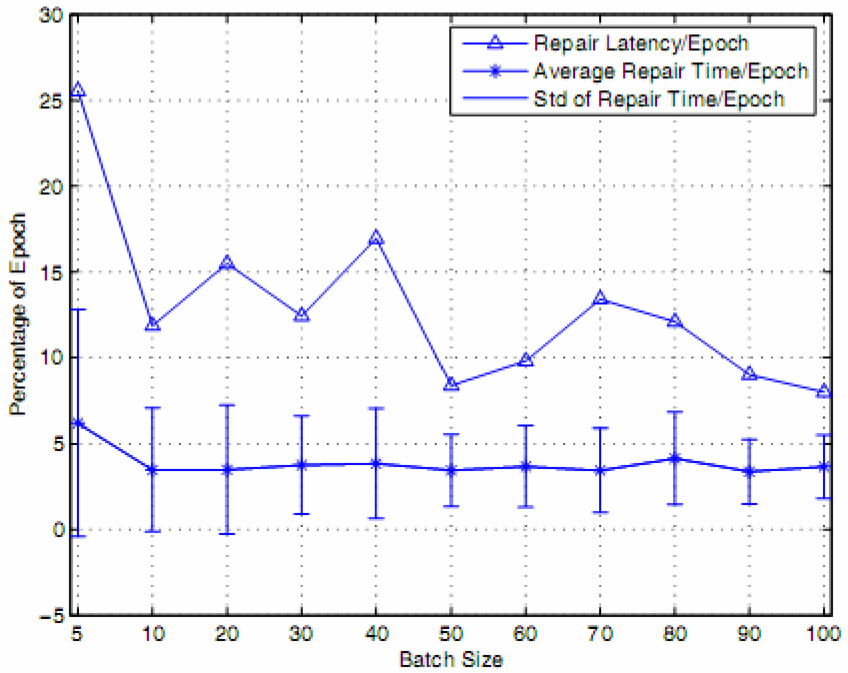


Fig. 5. Repair latency, average repair time and standard deviation of repair time under different batch size. MBMS loss rate is 0.3. Packet size is $1000 bytes$.

When batch size>10, it does not affect the protocol much

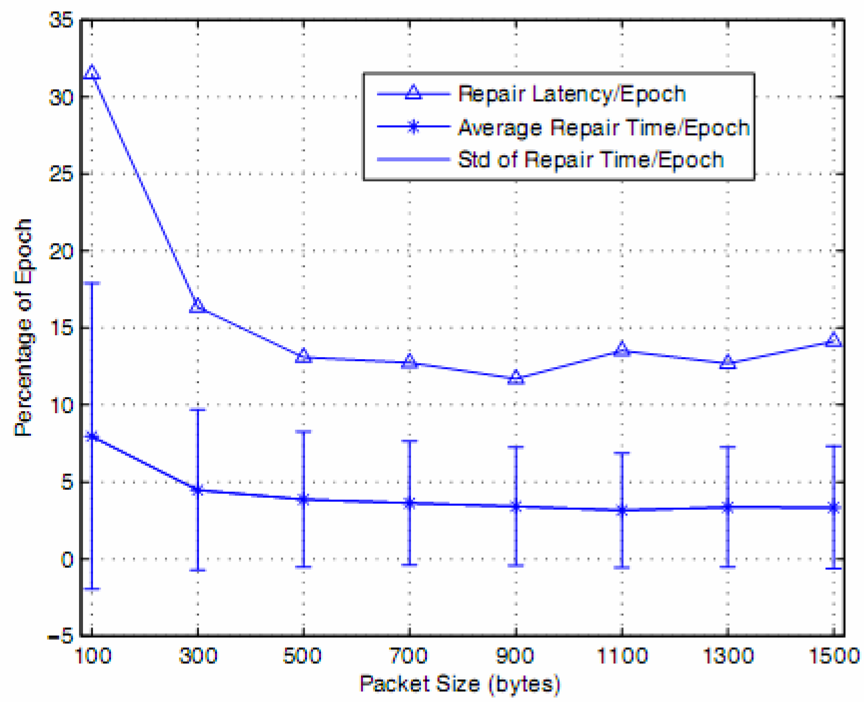


Fig. 6. Repair latency, average repair time and standard deviation of repair time under different packet size. MBMS loss rate is 0.3. Batch size is 10.

Homogeneous: uniformly distributed
Cluster: one cluster with 24 nodes and the other with 25 nodes; there is one node connecting these two clusters

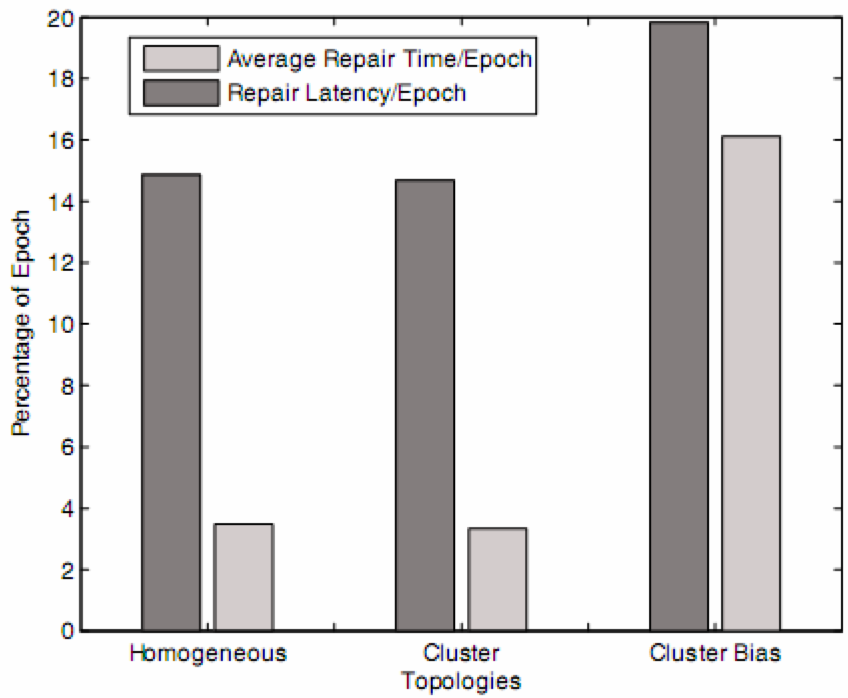


Fig. 7. Repair latency and average repair time under different topologies. MBMS loss rate is 0.3. Batch size is 10. Packet size is $1000 bytes$.

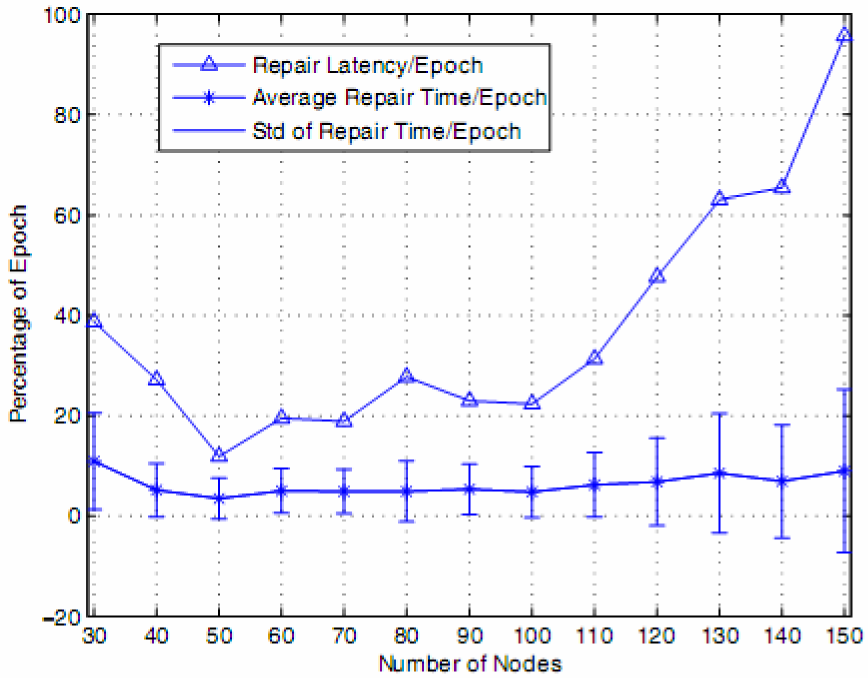


Fig. 8. Repair latency, average repair time and standard deviation of repair time under different number of nodes, MBMS loss rate is 0.3, Batch size is 10, Packet size is $1000 bytes$.

Conclusion

- Based on CPR protocol, NC-CPR is proposed to further reduce repair time
- Since NC-CPR is NP-Hard, heuristic based NC-CCPR and NC-DCPR are proposed
- Realistic concerns are addressed in NC-DCPR to enhance its adoption for practical use