Reliable Broadcast with Joint Forward Error Correction and Erasure Codes in Wireless Communication Networks

Pouya Ostovari and Jie Wu

Computer & Information Sciences
Temple University

Center for Networked Computing
http://www.cnc.temple.edu

Agenda

- Introduction
  - Motivation
- Cross-layer protection
  - Formulation
  - Proposed method
- Evaluations
- Conclusions

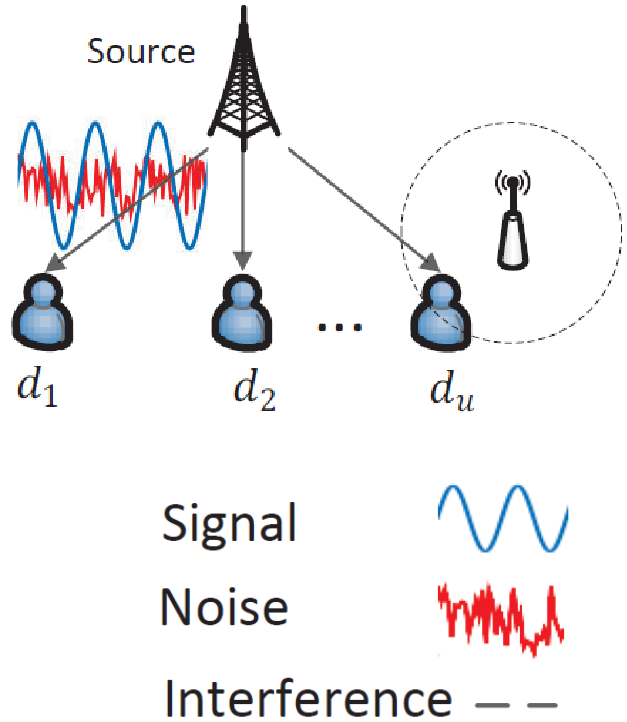
Introduction

- Advances in technology of mobile devices
  - Smartphones and tablets

- Wireless connections
  - Are widely used
  - Internet is accessible everywhere
- Reliable transmission
  - ARQ
  - Erasure codes
  - Hybrid-ARQ
  - Fountain codes (rateless codes)

Transmission Errors

- Noise
  - Forward error correcting codes (FEC)
  - Adding redundant bits to find and correct bit errors
  - Physical layer
- Interference
  - Packet erasure codes (EC)
  - Transmitting redundant packets
  - Application and network layers



Network Coding

- Random linear network coding
  - Linear combinations of the packets
  - Gaussian elimination

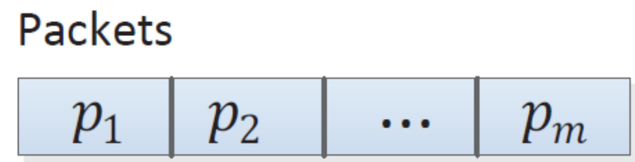
$$\begin{cases} q_1 = \alpha_{1,1}p_1 + \alpha_{1,2}p_2 + \alpha_{1,3}p_3 \\ q_2 = \alpha_{2,1}p_1 + \alpha_{2,2}p_2 + \alpha_{2,3}p_3 \\ \vdots \\ q_{\mathrm{n}} = \alpha_{n,1}p_1 + \alpha_{n,2}p_2 + \alpha_{n,3}p_3 \end{cases}$$

- Applications of network coding
  - Reliable transmissions
  - Throughput/capacity enhancement
    - Distributed storage systems/ Content distribution/ Layered multicast

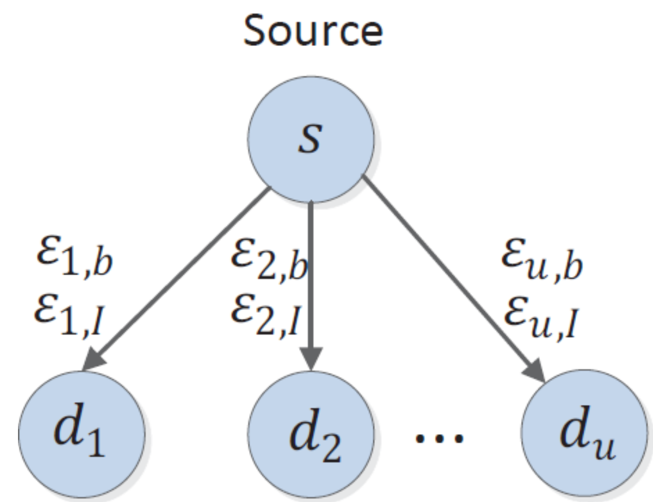
Cross-Layer Reliable Transmission

- Joint FEC and EC
  - Deciding about the amount of redundancy to be added for FEC and EC
- Previous work
  - Theoretic result for the case of single destination
  - Muriel Medard: implementation on sensor network
    - Shows that joint FEC-NC is effective
    - Depending on noise and interference level, more NC or FEC redundancy enhances the reliability
    - No method for redundancy distribution

Setting



- Single source
  - Transmits a set of *m* packets
  - Size of each packet: *n* bits
  - Source can transmit *X* bits

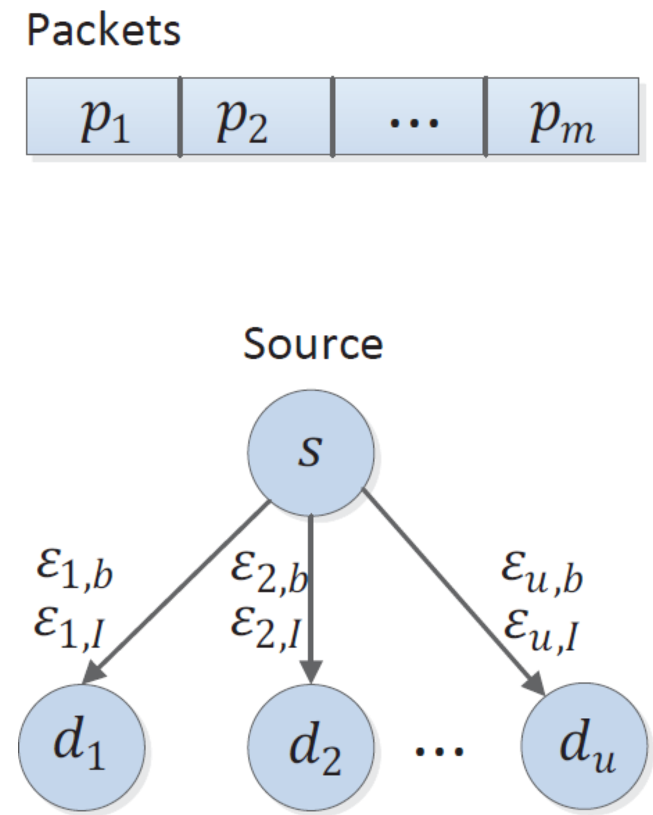


- Two sources of errors
  - Noise and interference
  - Different noise and interference probabilities

Setting

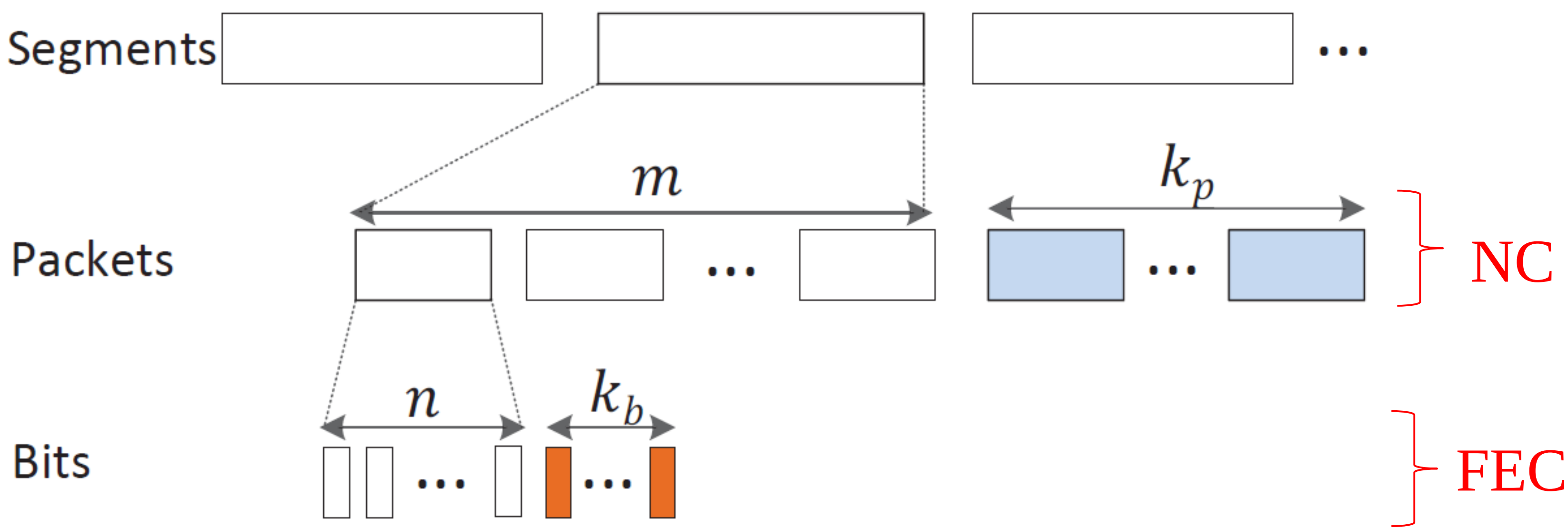
- Provide protection for the packets
  - Joint FEC and NC

- Objective
  - Finding the optimal transmission scheme that maximizes the probability of receiving the *m* packets by the destinations



Joint Coding Scheme

1. Segmentation
2. Applying network coding
3. Adding FEC to each network coded packet



Problem Formulation

- Erasure due to noise
  - When bit errors cannot be corrected

$$\epsilon_{i,e} = 1 - \sum_{j=n}^{n+k_b} \binom{n+k_b}{j} \epsilon_{i,b}^{n+k_b-j} (1-\epsilon_{i,b})^j$$

- Erasure due to noise and interference

$$\epsilon_i = \epsilon_{i,e} + (1-\epsilon_{i,e}) \times \epsilon_{i,I}$$

- Successful transmission of the *m* packets

$$q_i = \sum_{j=m}^{m+k_p} \binom{m+k_p}{j} {\epsilon_i}^{m+k_p-j} (1-\epsilon_i)^j$$

Problem Formulation

$$\max \prod_{i=1}^{u} q_i$$

$$s.t \quad q_i = \sum_{j=m}^{m+k_p} \binom{m+k_p}{j} {\epsilon_i}^{m+k_p-j} (1-\epsilon_i)^j, \ \forall i : 1 \le i \le u$$

$$\epsilon_{i,e} = 1 - \sum_{j=n}^{n+k_b} \binom{n+k_b}{j} \epsilon_{i,b}^{n+k_b-j} (1-\epsilon_{i,b})^j, \ \forall i : 1 \le i \le u$$

$$\epsilon_i = \epsilon_{i,e} + (1-\epsilon_{i,e}) \times \epsilon_{i,I}, \quad \forall i : 1 \le i \le u$$

$$(n+k_b) \times (m+k_p) \le X$$

Finding Optimal Distribution

- The probability equation cannot be simplified into a closed-form
- Two-phases algorithm
  - Offline phase: creating a reference table which shows the success delivery of the packets for each possible FEC and NC redundancy levels
  - Online phase: performing a search on reference table to find the optimal FEC and NC levels
    - Depending on the noise and interference probabilities of the users

Reference Table Creation

Algorithm 1 Reference Table Creation

Initialization: $h, j, k = 0$

Main:

for $k_b = 0$ to $k_b = (X - mn)/m$, step=g **do**

  $h = h + 1$ // Index for reference table

  $k_p = X/(n + k_b) - m$

  for $\epsilon_{i,b} = 0.05$ to 1, $step = 0.05$ **do**

    $j = j + 1$ // Index for bit error probability

    for $\epsilon_{i,I} = 0.05$ to 1, $step = 0.05$ **do**

      $k = k + 1$ // Index for interference probability

      Use Equation (1) to calculate $\epsilon_{i,e}$

      $\epsilon_i = \epsilon_{i,e} + (1 - \epsilon_{i,e}) \times \epsilon_{i,I}$

      Use Equation (3) to calculate q

      $Ref(h, j, k) = q$

Search for Optimal Coding Scheme

Algorithm 2 Search for Optimal Coding Scheme

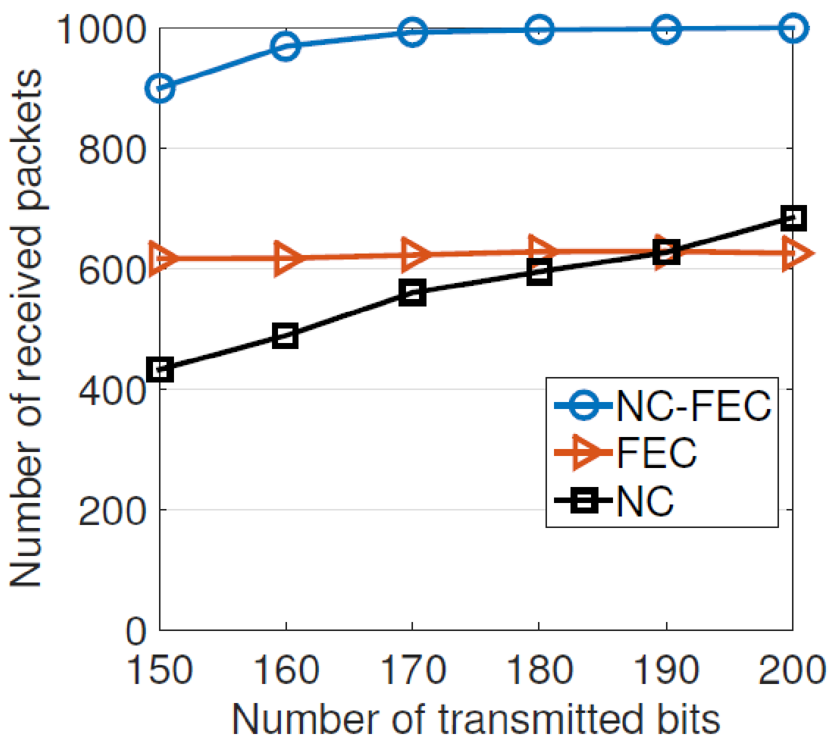
Initialization: $max = 0$
Main:
for Each strategy h in the reference table **do**
    $U = 1$
    for Each user u_i **do**
        Search the reference table to find q_i corresponding to $\epsilon_{i,b}$ and $\epsilon_{i,I}$
        $U = U \times q_i$
    if $U > max$ **then**
        $max = U$
        Mark strategy h as the selected policy

Evaluations

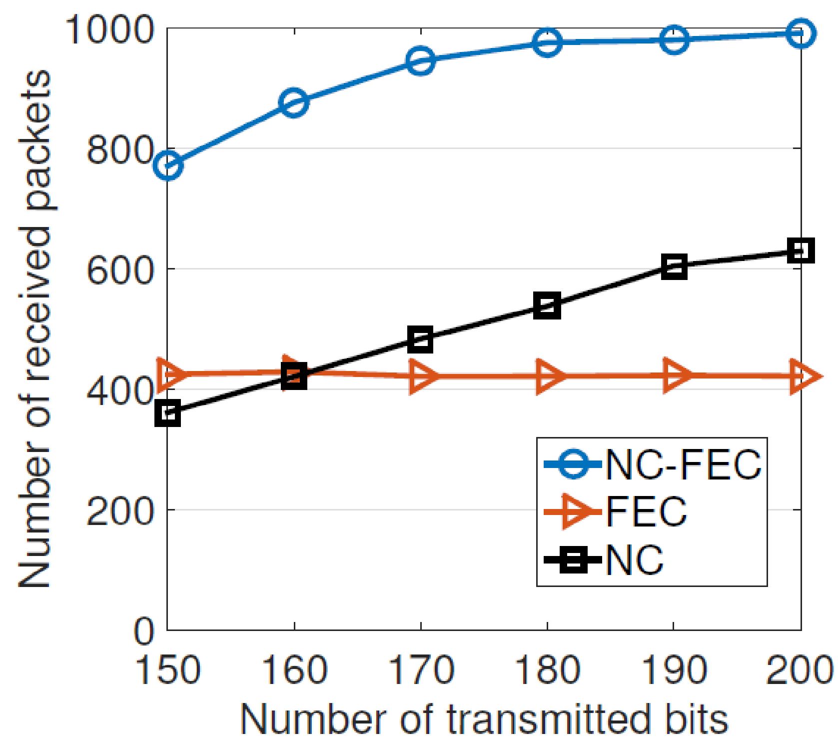
- Simulator in Matlab environment
- 1000 topologies with random bit error rate and interference probability
- Bit error rate and interference probability of the destinations are independent
- Comparing with only FEC and only NC methods

Evaluations

- 100 sets of packets
  - Each set contains 10 packets



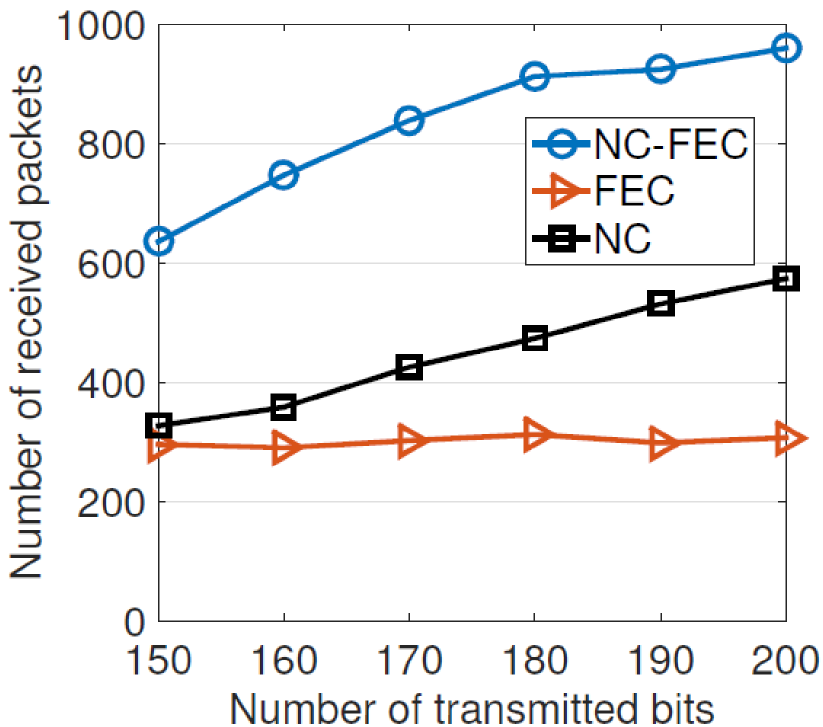
$\epsilon_{i,b} \in [0, 0.1]$, $\epsilon_{i,I} \in [0, 0.1]$



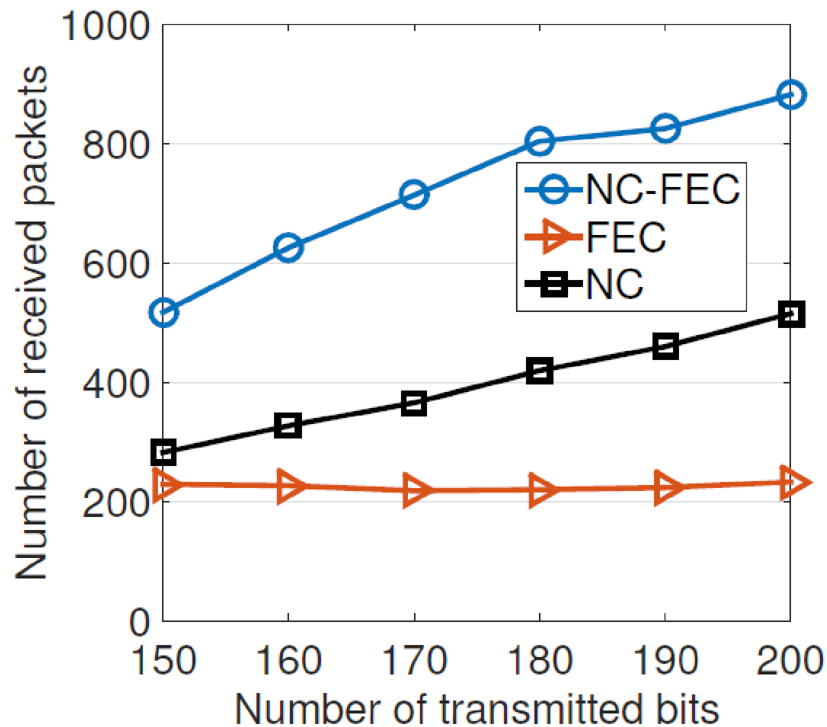
$\epsilon_{i,b} \in [0, 0.1]$, $\epsilon_{i,I} \in [0, 0.2]$

Evaluations

- 100 sets of packets
  - Each set contains 10 packets



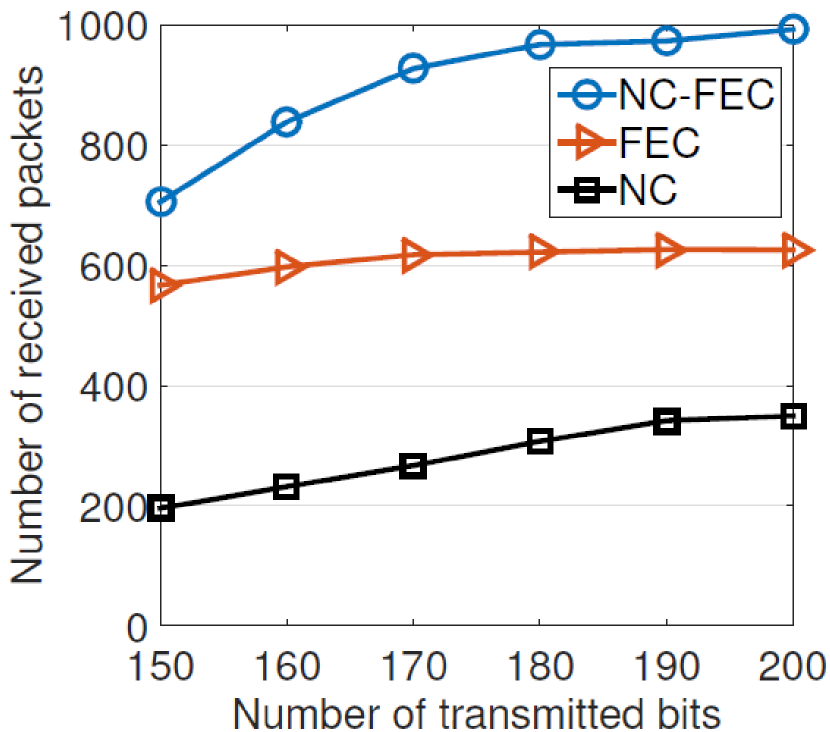
$\epsilon_{i,b} \in [0, 0.1], \epsilon_{i,I} \in [0, 0.3]$



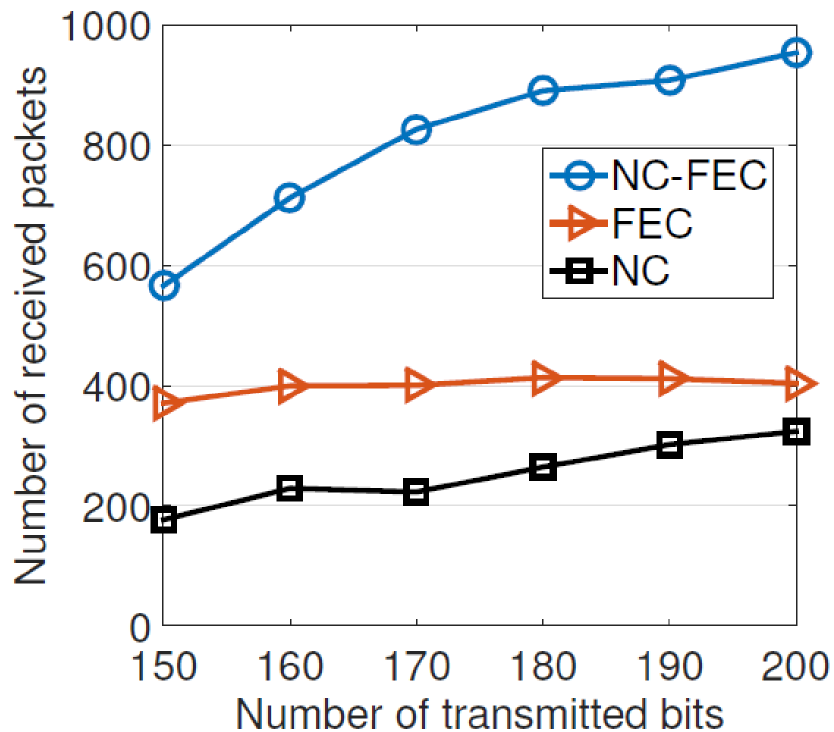
$\epsilon_{i,b} \in [0, 0.1], \epsilon_{i,I} \in [0, 0.4]$

Evaluations

- 100 sets of packets
  - Each set contains 10 packets



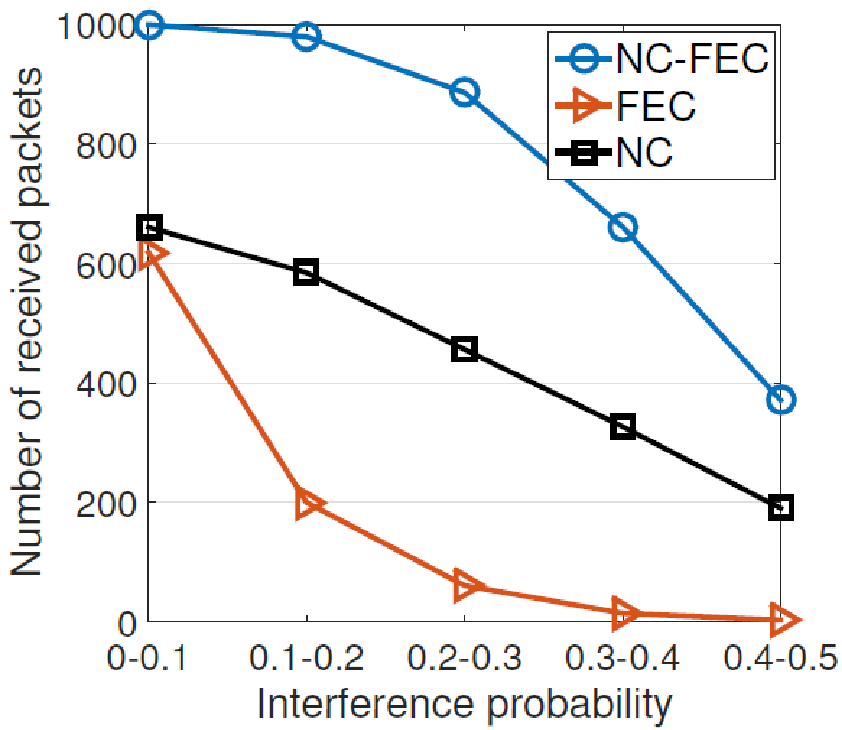
$\epsilon_{i,b} \in [0, 0.2]$, $\epsilon_{i,I} \in [0, 0.1]$



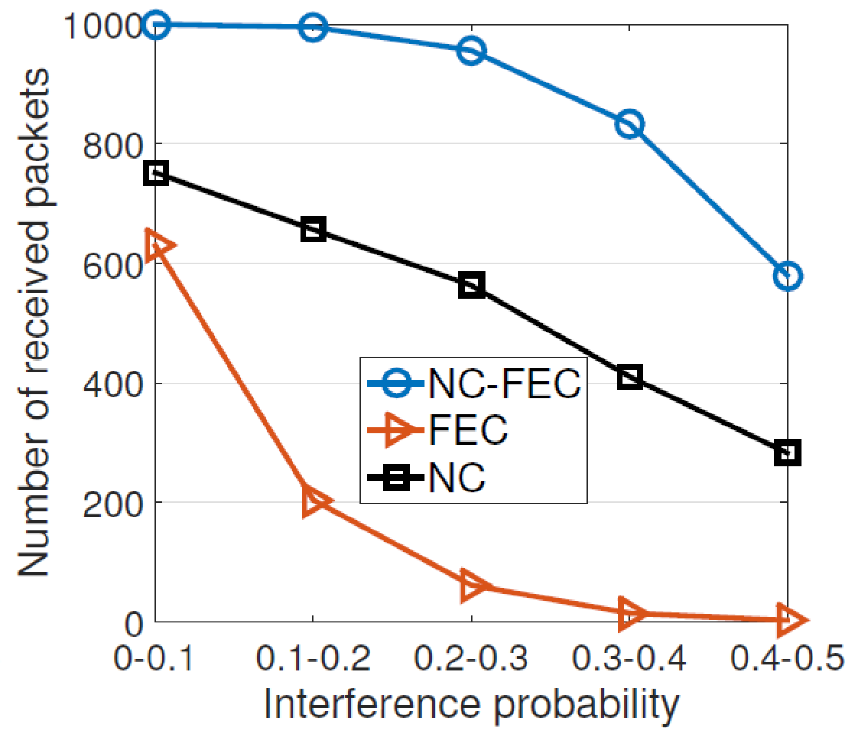
$\epsilon_{i,b} \in [0, 0.2]$, $\epsilon_{i,I} \in [0, 0.2]$

Evaluations

- 100 sets of packets
  - Each set contains 10 packets



$\epsilon_{i,b} \in [0, 0.1],\ X = 200$



$\epsilon_{i,b} \in [0, 0.1],\ X = 220$

Simulation Summary

- For low noise probability FEC provides a better protection
- As noise or interference probability increases, more redundancy is needed for NC (EC)
  - FEC performs poorly
- FEC or NC?
  - For a given noise and interference probability, that depends on X

Conclusion

- Cross-layer protection of transmitted packets
- Joint FEC and NC to enhance reliability
- Fixed redundancy
- Finding the optimal transmission scheme
  - FEC redundancy
  - NC redundancy (erasure code)
- Two-phases algorithm
  - Offline and online phases

Thank you