Wireless Network Coding
from Theory to Practice

- How to use network coding in practical scenarios?
- Design network coding schemes.
- How much is the performance benefit?
- Are these schemes implementable?
Network Coding in Wireless Networks?
Two concrete application scenarios

Scenario 1: Mesh Networks
- \([I^2NC: \text{INFOCOM'11}]\)
  - unicast TCP flows, multihop wireless mesh networks
  - one-hop, inter-session network coding, right above the MAC layer

Scenario 2: Collaborative Smartphones
- \([\text{MicroCast: Allerton'11}]\)
  - one multicast video streamed to several smartphones
  - intra-session network coding at the application layer
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Scenario 1: Wireless Mesh Networks

- Multi-hop wireless mesh networks
- One-hop, inter-session network coding (like COPE)
- Challenges: TCP unicast flows, high loss
How to deal with loss?

E2E Mechanisms (e.g. robust TCP)

Mechanisms in the middle (e.g. NCAQM)
A collaboration within this MURI

I^2NC: combines inter- and intra-session network coding

- An internship at AT&T, Summer 2010
**I²NC: Intra- and Inter-session NC**

Functionality at intermediate node I

- **Inter-session coding:** what percentage of flows should be **coded** together
- **Intra-session coding:** how much redundancy to add and on which flow
- **Communication:** what information should nodes exchange
  - I²NC-state: overheard packets at neighbors (as COPE)
  - I²NC-stateless: loss rates on direct and overhearing links
Network Utility Maximization

$I^2$NC-stateless: Formulation

\[ \max_{x,\alpha,\tau} \sum_{s \in S} U_s(x_s) \]

s.t.
\[ \frac{H^s_{h,k} \alpha^s_{h,k} x_s}{1 - \rho^s_h} + \sum_{s' \in S_k - \{s\}} \frac{H^s_{h,k} \alpha^s_{h,k} x_{s'} \rho^{s,s'}_{h,k}}{1 - \rho^s_h} \leq R_h \tau_{h,k}, \]

\( \forall h \in A, k \in K_h, s \in S_k \)

\[ \sum_{h(J) \in A} \sum_{k \in K_h} \alpha^s_{h,k} = 1, \quad \forall s \in S, i \in P_s \]

\[ \sum_{h \in C_q} \sum_{k \in K_h} \tau_{h,k} \leq \gamma, \quad \forall C_q \subseteq A \]

Interference

Flow conservation

Capacity constraint
Network Utility Maximization

I$^2$NC-stateless: Solution

- **Rate Control:**
  \[ x_s = (U_s')^{-1} \left( \sum_{i \in P_s} Q_i^s \right) \]
  where
  \[ Q_i^s = \sum_{h(J) \in A} \sum_{k \in K_h} H_{h,k}^s \alpha_{h,k}^s Q_{h,k}^s \]
  and
  \[ Q_{h,k}^s = \frac{q_{h,k}^s}{1 - \rho_h^s} + \sum_{s' \in S_k \setminus \{s\}} \frac{q_{h,k}^{s'}}{1 - \rho_h^{s'}} \rho_{h,k}^{s,s'} \]

- **Queue Update:**
  \[ q_{h,k}^s(t + 1) = \left\{ q_{h,k}^s(t) + c_t \left[ \frac{H_{h,k}^s \alpha_{h,k}^s x_s}{1 - \rho_h^s} + \sum_{s' \in S_k \setminus \{s\}} H_{h,k}^{s'} \alpha_{h,k}^{s'} x_s \rho_{h,k}^{s,s'} \right] - R_h \tau_{h,k} \right\}^+ \]

- **Traffic Splitting:**
  \[ \min_{\alpha} \sum_{h(J) \in A} \sum_{k \in K_h \setminus \{s\}} \alpha_{h,k}^s H_{h,k}^s Q_{h,k}^s \]
  subject to
  \[ \sum_{h(J) \in A} \sum_{k \in K_h \setminus \{s\}} \alpha_{h,k}^s = 1, \forall i \in P_s \]

- **Scheduling:**
  \[ \max_{\tau} \sum_{h \in A} \sum_{k \in K_h \setminus \{s\}} \sum_{s' \in S_k} q_{h,k}^s R_h \tau_{h,k} \]
  subject to
  \[ \sum_{h \in C_q \subseteq A} \tau_{h,k} \leq \tau, \forall C_q \subseteq A \]
Integration in the protocol stack
Performance evaluation
Multi-hop topology

TCP traffic

UDP traffic

- Resilient to loss, significant throughput increase (up to 50%)
- Added benefit: no need to know the exact state of neighbors
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Scenario 2: Smartphones

- Several smartphone users, within proximity of each other
- Interested in viewing the same video at the same time
- Video stored on the cloud or on one of the phones
• **Question:**
  - How to best (good user experience, low cost) utilize downlink (cellular, wifi) and local (wifi, bluetooth) links?

• **Key ingredients of MicroCast:**
  - **Cooperation:** use downlink and local links
  - **Network coding:** intra-session, application-layer
  - **(Pseudo) broadcast**
NUM Formulation

- Network coding + cooperation + (pseudo)broadcast

\[
\max_x U(x) \quad \text{Optimize video rate: } x
\]

\[
\sum_{i \in N} x_{i,j} - x \geq 0, \forall j \in N
\]

Flow conservation constraints

\[
 g_{i,j} - x_{i,j} \geq 0, \forall i \in N, j \in N
\]

Downlink and local area capacity constraints

\[
x_{i,j} \leq C_i (1 - p_i), \forall i \in N, j \in N
\]

\[
g_{i,j} \leq \sum_{J \mid j \in J} f_{i,J}, \forall i \in N, j \in N
\]

\[
f_{i,J} \leq \min\{C_{i,j} (1 - p_{i,j})\} \tau_{i,J}, \forall i \in N, J \in H
\]

\[
\sum_{i \in N} \sum_{J \in H} \tau_{i,J} \leq \gamma
\]

Interference
NUM Solution

- What do we learn from it? [Allerton'11]
  - Optimal downlink rate and device-device rates.
  - What information needs to be exchanged?

- MicroCast implementation mimics the optimal solution
  - Allows to share a video stream, local or remote (HTTP) MP4
Implementation

Hardware

• Hardware platform
  – Google Nexus S
    • 1 GHz Cortex A8, 512 MB RAM

• Network connections
  – Connection to the Internet:
    • cellular or
    • 802.11b infrastructure mode
  – device-to-device:
    • Bluetooth 2.1+EDR
    • 802.11 ad-hoc mode
# Implementation

## Software

- **Software platform**
  - Android 2.3
  - Application written in Java runs on
    - Android (mobile phones, tablets)
    - Java 2 SE (laptops, etc.)

## Diagram

![Diagram of Android software components](image_url)

- **Applications and Widgets**
  - Home
  - Contacts
  - Browser
  - Widgets
  - Your App Here

- **Application Framework**
  - Activity Manager
  - WindowManager
  - Content Providers
  - View System
  - Notification Manager
  - Location Manager
  - Sensor Manager

- **Libraries**
  - Surface Manager
  - OpenGL ES
  - Media Framework
  - SQLite
  - FreeType
  - WebKit
  - SSL
  - libnc

- **Android Runtime**
  - Core Libraries
  - Dalvik Virtual Machine

- **Linux Kernel**
  - Display Driver
  - Bluetooth Driver
  - Camera Driver
  - Flash Memory Driver
  - Binder (IPC) Driver
  - Power Management

- **Keypad Driver**
  - USB Driver
  - WIFI Driver
  - Audio Drivers
Application Architecture

Video player

Segment reordering and caching

Requester

Abstraction layer

HTTP Worker

Downlink: Wifi/3G

Local Collaboration

Abstraction layer

Local link: Bluetooth/WiFi
Testbed

HTTP Server

802.11 AP

1 2

3 4
Scheme 1: Baseline

use only downlinks, no cooperation, no NC
Scheme 2: MicroCast

downlink+local links, cooperation, application-layer NC
Watch the video/proof-of-concept by Lorenzo Keller (@EPFL)

at www.muri.princeton.edu
and http://odysseas.calit2.uci.edu/doku.php/public:muri09
3. Further Improving Microcast: Exploiting pseudo-broadcast

- Unicast connections do not fully exploit the broadcast nature of the wireless medium
- **Broadcast** not the best option
- **Pseudo-broadcast** on androids is challenging
  - Overhearing mode not enabled
  - No API: we had to extend the Android API to support it
Watch the video/proof-of-concept by Blerim Cici (@UCI)

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Wireless Network Coding
Summary and Ongoing Work

Practical Scenarios
1. Mesh Networks [I2NC: INFOCOM’11]
2. Collaborative Smartphones [MicroCast: Allerton’11]

From Theory to Practice
• Design rooted at theory
• Implementation challenges

Ongoing work and current focus
• Network coding on smartphones
• http://odysseas.calit2.uci.edu/doku.php/public:muri09
Participants

UCI: Athina Markopoulou (faculty - co-PI in MURI), Hulya Seferoglu (postdoc), Anh Le and Blerim Cici (grad students).

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Funded by AFOSR MURI (FA9550-09-0643) and NSF CAREER