Analog Network Coding

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Current Wireless

Router
Current Wireless

Traditional Routing requires 4 time slots
Current Wireless

Router

Traditional Routing requires 4 time slots
Traditional Routing requires 4 time slots
COPE

Traditional Routing requires 4 time slots
Traditional Routing requires 4 time slots

COPE requires 3 time slots

Can we do it in 2 time slots?
Instead of router mixing packets...

Exploit that the wireless *channel naturally mixes signals*

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**Analog Network Coding (ANC)**
Analog Network Coding
Analog Network Coding

1) Dina and Jon transmit simultaneously
Analog Network Coding

1) Dina and Jon transmit simultaneously

2) Router amplifies and broadcasts interfered signal
Analog Network Coding

1) Dina and Jon transmit simultaneously
2) Router amplifies and broadcasts interfered signal
3) Dina subtracts known signal from interfered signal
Analog Network Coding

1) Dina and Robert transmit simultaneously
2) Router amplifies and broadcasts interfered signal
3) Dina subtracts known signal from interfered signal

Analog Network Coding requires 2 time slots
→ Higher throughput
It Is More Than Going From 3 To 2!

- Philosophical shift in dealing with interference
  - Strategically exploit interference instead of avoiding it

- Promises new ways of dealing with hidden terminals
Hidden Terminal Scenario

Src -> R1 -> R2 -> Dst
Hidden Terminal Scenario

1) Src and R2 transmit simultaneously
1) Src and R2 transmit simultaneously
2) R1 subtracts P1, which he relayed earlier to recover P2 that he wants
Hidden Terminal Scenario

R2 and Src are hidden terminals

- Today : Simultaneous transmission → Collision
- ANC : Simultaneous transmission → Success!
Hidden Terminal Scenario

Other Benefits of ANC:
- First step toward addressing hidden terminals
- ANC extends network coding to new scenarios
How do we make it work?
Practical Challenges

- Interfered signal is not exactly the sum
  - Channel distorts signals
  - Two signals are never synchronized
  - It is not $s_D(t) + s_J(t)$ but $f1(s_D(t)) + f2(s_J(t-T))$

Prior work assumes full synchronization and ignores channel distortion

Not Practical!
Key Idea: Exploit Asynchrony!
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- Dina uses interference-free parts to estimate channel and timing
- Dina compensates for her interfering signal

Exploit asynchrony to make it practical
Cross layer realization of our idea
Protocol

- Router senses idle medium and broadcasts a trigger to Dina and Jon
- Dina and Jon jitter their start times randomly and transmit
- Router amplifies and forwards interfered signal
- Dina and Jon receive and decode

How do they decode?
Primer on Modulation

- Nodes transmit vectors on channel
- Focus on MSK (Minimum Shift Keying) modulation

D2 leads D1 by 90 degrees → Bit “1”

D2 lags D1 by 90 degrees → Bit “0”
**Primer on Channel Effects**

**Attenuation**

D2 and D1 are attenuated by the same amount.
Primer on Channel Effects

- Attenuation
- Rotation

D1

Channel

D2

D1
Primer on Channel Effects

- Attenuation
- Rotation

To decode, receiver computes angle between received vectors

\[ \text{Angle (D2, D1)} = 90 \text{ degrees} \Rightarrow \text{Bit “1” was transmitted} \]
So, How Does Dina Decode?
So, How Does Dina Decode?

- Small uninterfered part at the start
- Decodes uninterfered part via standard MSK demodulation
- Once interference starts, Dina changes decoding algorithm
What did Dina send?
What did Dina send?
What did Jon send?
What is Interference → Vector addition
What does Dina know?
What does Dina know?

Amplitude of her Vectors → α

Amplitude of Jon’s Vectors → β

No Interference
What does Dina know?

Dina finds solutions for $X_1$ and $X_2$
What does Dina know?

Two solutions for each interfered vector!
What does Dina know?

Four possible angles!
What does Dina know?

Four possible angles!
What does Dina know?

Four possible angles!
What does Dina know?

Four possible angles!
What does Dina know?

Four possible angles!
What does Dina know?

Pick the correct angle $\rightarrow$ 90 degrees
What does Dina know?

Pick the correct angle $\rightarrow$ +90 degrees
What does Dina know?

Dictates solution for Jon’s vectors!
What does Dina know?

Dina finds angle between $J_1$ and $J_2$ and decodes
Decoding Algorithm – Decoding interference

- Decode rest of the interfered part using this algorithm
- Decode final uninterfered part from Jon via standard MSK demodulation
Performance
ANC Implementation

- Software – GNURadio codebase
- Hardware – USRP frontend
- 2.4-2.48 GHz frequency range
- SNR of 20-30 dB
- Canonical topologies in mesh networks
Dina and Jon

- ANC throughput gain over current: $4/2 = 2$
- ANC throughput gain over COPE: $3/2 = 1.5$
Throughput gain for Dina-Jon scenario

Median Gain over Routing – 70%
Throughput gain for Dina-Jon scenario

Median Gain over Routing – 70%
Median Gain over COPE – 30%
X topology

Router

Interference

Capture!

Capture!
X topology

Router

Interference

Capture!

Capture!
ANC decodes interference using overheard signals
Throughput gain – X topology

Median Gain over Routing – 65%
Throughput gain – X topology

CDF

Throughput gain

Gain over COPE

Gain over Routing

Median Gain over Routing – 65%
Median Gain over COPE – 28%
Chain topology

ANC throughput gain over current $3/2 = 1.5$
Throughput gain – Chain topology

Median Gain over Routing – 37%
Conclusion

- Shifts in the design of wireless networks to recognize wireless for what it is
  - Embrace Broadcast
  - Embrace Interference

- Implementation that yields large throughput gains
Comments?
Comments

• Pros
  – Make analog network coding practical
  – Don’t need synchronization
  – More efficient than digital network coding

• Cons
  – Performance benefit is high only under high SNR region (e.g., 20 dB)
  – Requires similar packet sizes, and don’t support different packet sizes
  – Works for only 2 simultaneous senders
  – Decoding works for MSK
  – Performance benefits over digital network coding is around 30% under motivating scenarios, and might become too small to justify its complexity in general networks
  – How to schedule transmissions to exploit ANC benefit is open