Embracing Wireless Interference : Analog Network Coding

By Sachin Katti, Shyamnath Gollakota, and Dina Katabi

Shyamala Villupuram Sundararaman
University of Freiburg
Institute für Informatik
Winter Semester 2009/10

Over View

- Traditional Wireless Network
- What is Network Coding?
- Embracing Wireless Interference : Analog Network Coding (ANC)
- Comparing Throughput gain of ANC using transmission networks
  - Uni – Directional Transmission Network
  - Bi – Directional Transmission Network
- Implementation of Analog Network Coding
  - Modulation/Demodulation Technique
- Synchronization and Channel Status
- Future Works
- Conclusion

Traditional Network

- Transmits packets
  - Sender → Router → Receiver.
- Avoid Collision.
- No throughput gain.
- Best approach to improve throughput gain
  - Network Coding Approach

Network Coding

- Method of attaining maximum information flow in a network
  - Also allows senders to transmit packet simultaneously
  - Approaches
    - Digital Network Coding
    - Analog Network Coding
- Digital Network Coding
  - Packets are transmitted one after the other.
  - Router XORs the packets and transmit packet to their corresponding destinations.
  - Throughput gained a bit than traditional approach.

Analog Network Coding

- Analog Network Coding
  - Supports wireless interference.
  - Nodes are allowed to transmit packets simultaneously.
  - Collision occurs at router node.
  - Router node adds the colliding signals and transmits to their corresponding destinations.
  - Throughput gain is more comparing to traditional network and digital network coding approaches.
- Difference between digital and analog network coding
  - Analog Network Coding
    - Nodes transmits packets simultaneously.
    - Done at physical layer.
  - Digital network coding
    - Nodes transmits packets one after the other.
    - Done at data link layer

Illustrative Example

- Comparing throughput gain of ANC using two transmission networks
  - Uni – Directional Transmission Network
  - Bi – Directional Transmission Network

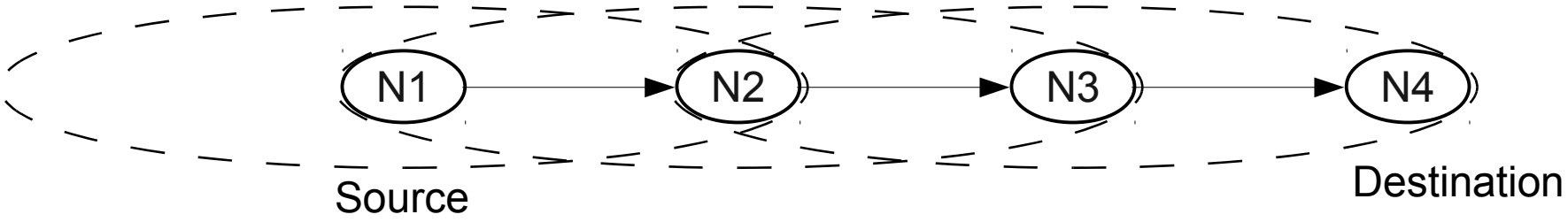
Uni – Directional Transmission Network

- Traditional Network approach – hop by hop transmission
  - Needs 3 time slots.
- Digital Network Coding
  - Cannot reduce time slot
- Analog Network Coding
  - Allows simultaneous transmission of packets.
  - Assume synchronization of packets at node N2.
  - Node N2 stores copy of Mi sent by Node N1.
  - Mi+1 and Mi collide at node N2 – receives interfering signals ((Mi+1)$\oplus$Mi). Stores inverse of Mi sent by node N3.
  - Cancels the interfering signals by performing

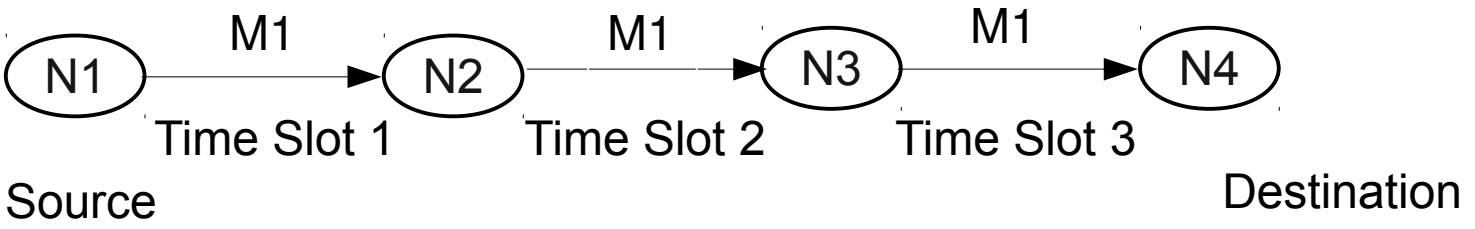
    ((Mi+1)$\oplus$Mi)$\oplus$ Mi^{-1} = (Mi+1).
  - Time slots reduced from 3 to 2 – nodes N1 and N2 transmit packets simultaneously.
  - Throughput gained 3/2 = 1.5

Illustrative Example

- Uni – Directional Transmission Network

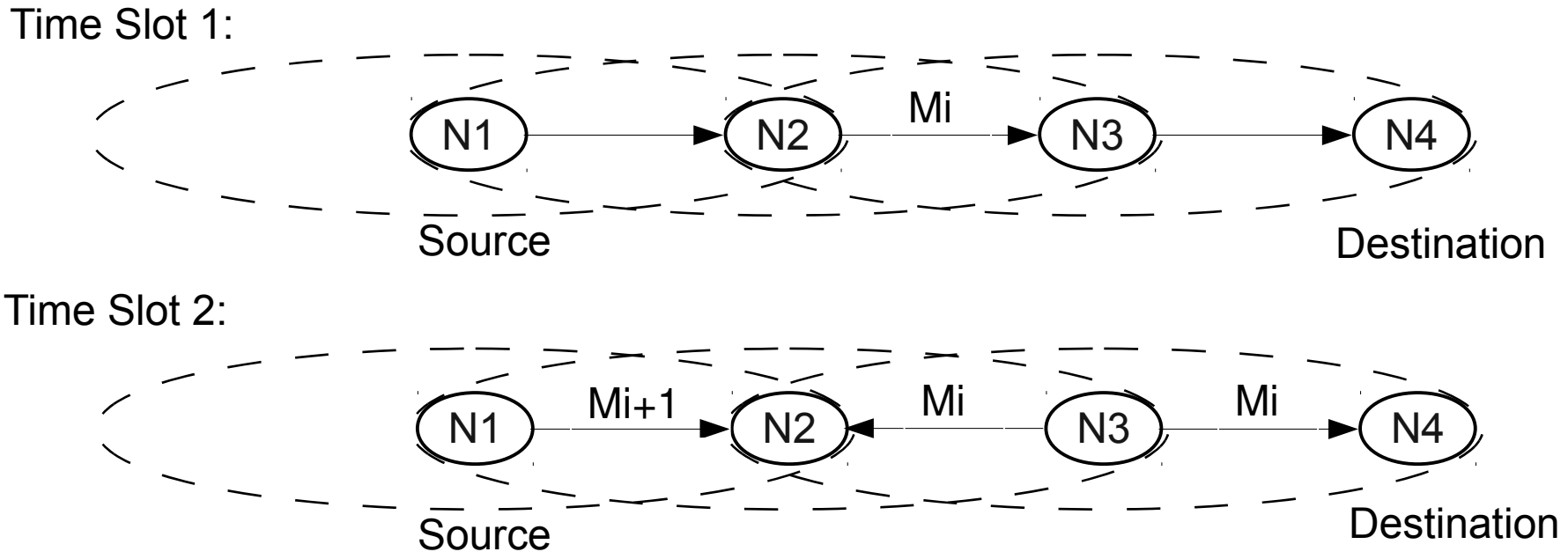


  - Traditional Network Approach
    - Message M1 transmitted from source to its destination



Illustrative Example

- Analog Network Coding Approach

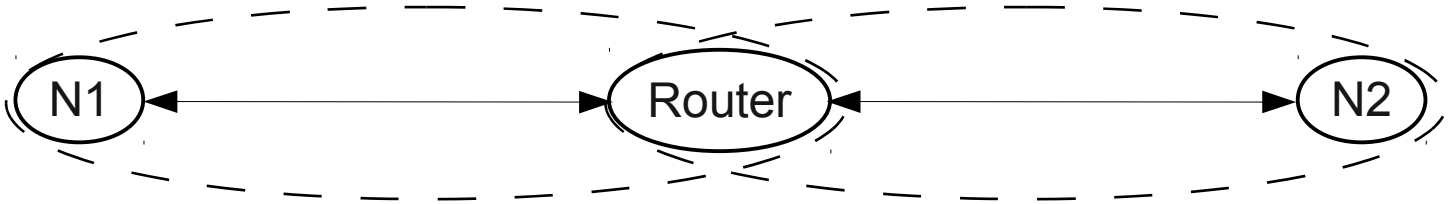


Bi – Directional Transmission Network

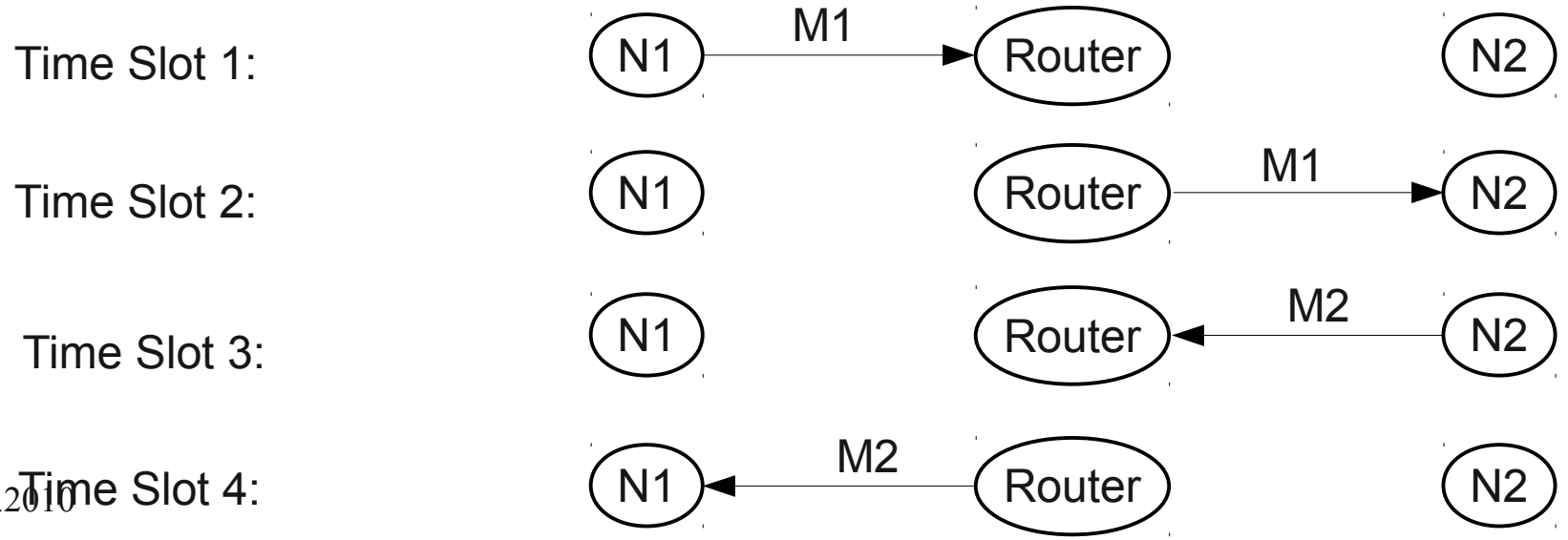
- Traditional Network Approach
  - Needs 4 time slot to deliver packet
- Digital Network Coding Approach
  - Transmits packets one after the other.
  - Router XORs the packets M1⊕M2 and forwards XORed version.
  - Transmission steps reduced from 4 to 3
  - Throughput gained 4/3 = 1.3
- Analog Network Coding Approach
  - Transmits packets simultaneously.
  - Router uses modulation/demodulation technique to deliver packets.
  - Router adds two signals and decode and forwards those signals.
  - Transmission steps reduced from 4 to 2.
  - Throughput gained 4/2 = 2

Illustrative Example

- Bi – Directional Transmission Network



  - Traditional Network Approach



Illustrative Example

- Digital Network Coding Approach

  Router's Performance with example

  XOR operation:

  M1 = 1101; M2 = 1010

  Router = M1⊕ M2 = 0111

  At Node N1:

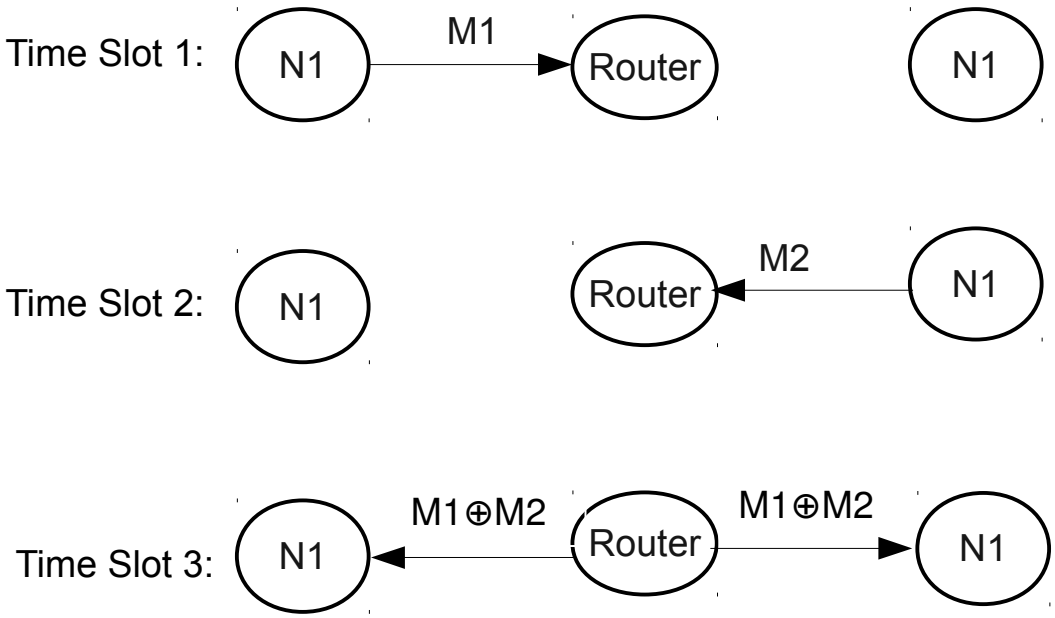
  M1 ⊕ (M1⊕ M2) = (M1⊕ M1) ⊕ M2

  = 0 ⊕ M2 = M2 = 1010

  At Node N2:

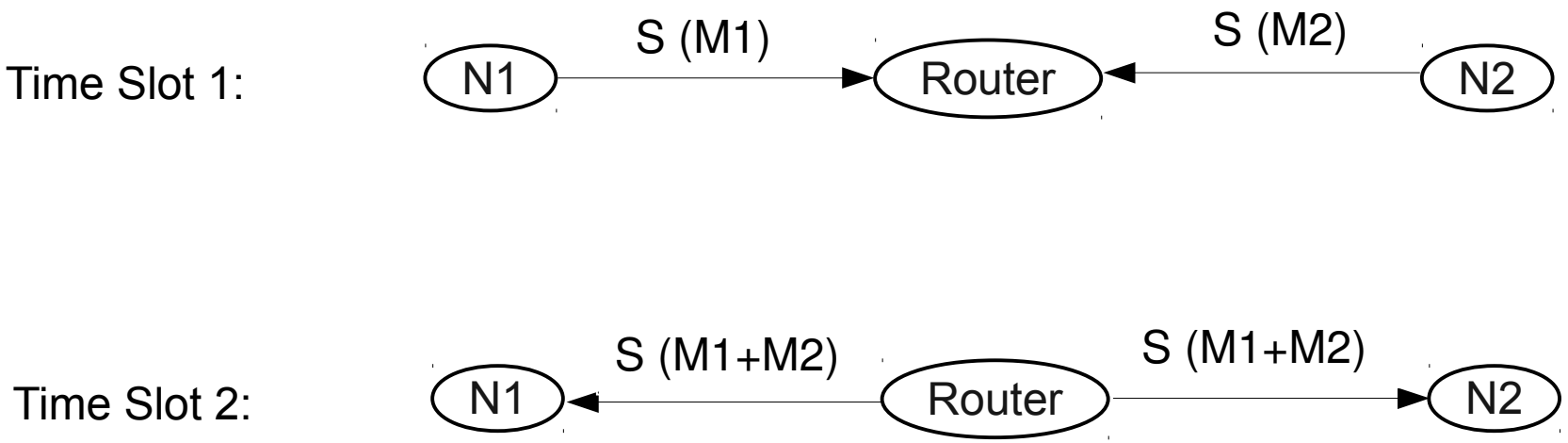
  M2 ⊕ (M1⊕ M2) = M1⊕ (M2⊕ M2)

  = M1⊕ 0 = M1 = 1101



Illustrative Example

- Analog Network Coding



Implementation of ANC using Modulation/demodulation Technique

- Modulation/Demodulation Technique
  - Bi – directional transmission network
  - Modulation - Transmission of information signal and carrier signal over communication medium.
  - QPSK – Quadrature Phase Shift Keying modulation – used for implementing ANC
    - Carrier signal sent in four possible phases 0°, 90°, 180°, 270°.
    - Digit '0' - phase difference of 0°and less.
    - Digit '1' - phase difference of 90°and more.
    - Two bits of information is delivered for each time slot

Phases	Bits
0°	00
90°	01
180°	10
270°	11

Modulation/demodulation at Router

- Router receives sum of two simultaneous signals from N1 and N2,

$$R(M) = S(M1) + S(M2)$$
$$= [x1\cos(t) + y1\sin(t)] + [x2\cos(t) + y2\sin(t)]$$
$$= (x1+x2)\cos(t) + (y1+y2)\sin(t)$$

  - Two cosine waves – in-phase signal
  - Two sine waves – quadrature phase signal

$$I = x1 + x2$$
$$Q = y1 + y2$$

Treating In-Phase and Quadrature phase as digital bit streams

- Final messages are delivered in binary bits.
- Each time slot 2 bits of information is delivered.
- Router receives XORed version of in-phase and quadrature phase
  - In-Phase :

    $Si\ (M1 + M2) = Si\ (M1) \oplus Si\ (M2)$
  - Quadrature Phase :

    $Sq\ (M1 + M2) = Sq\ (M1) \oplus Sq\ (M2)$
- Router R (M) transmits the following signal to node N1 and node N2:
  - $S(M1 + M2) = x3\cos(t) + y3\sin(t)$

Modulation/demodulation at router R(M)

- Modulation/demodulation at router

In-Phase Binary Bits		Xk = 2N-1	
Si (M1)	Si (M2)	X1	X2
0	0	-1	-1
0	1	-1	1
1	0	1	-1
1	1	1	1

Table 2(a) Modulation at node N1 and N2

Demodulation at R (M)	XOR Operation at R (M)	Nodes N1 Receives
X1+X2	Si (M1+M2)	S (M1)
-2	0	-1
0	1	1
0	1	1
2	0	-1

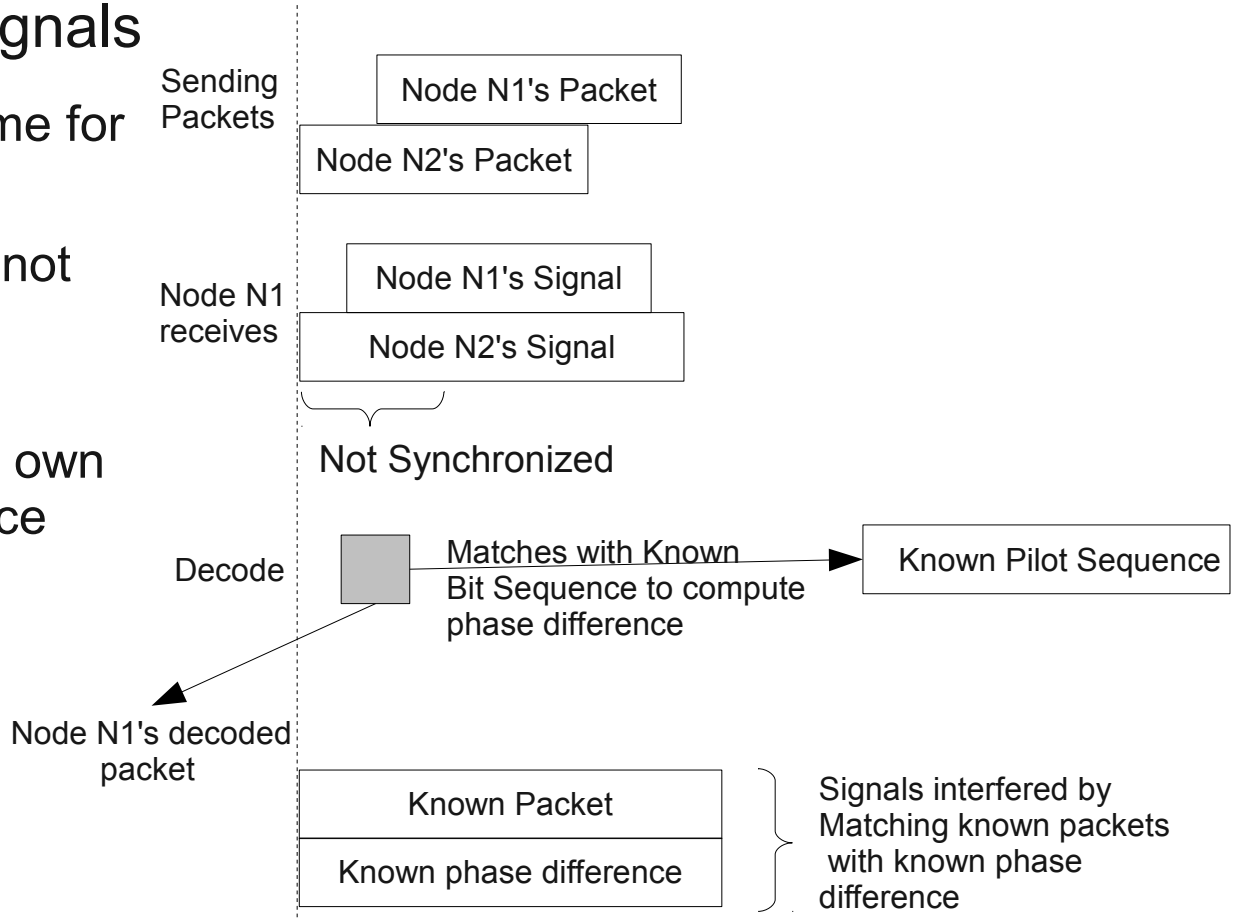
Table 2(b) Demodulation at router R (M)

Problems in Sending Packets

- Problem(s)
  - Synchronization at the router
    - Signals of nodes N1 and N2 does not arrive router at the same time.
- Solution
  - Pilot symbol approach
    - Estimates synchronization of signals and channel status.
    - Inserting 64-bit length sequence at the beginning and end of each packet before transmission.

Synchronization of signals and Channel Status

- Synchronization of two signals
  - Assume packet size is same for N1 and N2.
  - Node N1 and N2's packet not interfered at the router simultaneously.
  - Node N1 and N2 aligns its own packet and phase difference
  - Node N1 and N2's packet matches at router
  - Router applies usual modulation/demodulation technique



Future Works

- Theoretically shown the throughput gain of ANC but practically run ANC on approaches discussed above.
- ANC shown for only three-node network. Test ANC for huge network.
  - Improves Bit Error Rate in small networks.
- Check with different packet sizes – synchronization and channel status.

Conclusion

- Analog Network Coding proved that
  - Throughput is higher than traditional approaches and digital network coding approach.
  - Implemented ANC using modulation/demodulation technique.
  - ANC works fine in small networks.
- However, Analog Network Coding needs further research to improve the technology.

References

[1] S. Katti, S. Gollakota, D. Katabi, Embracing Wireless Interference: Analog Network Coding, Proceedings of the 2007 conference on Applications, technologies, architectures and protocols for computer communications; Session:Wireless, Pages: 397-408, 2007.

[2] D.N.C. Tse and G.W Wornell. Cooperative diversity in wireless networks: ecient protocols and outage behavior, IEEE Trans. Inform. Theory; Volume 50, Pages: 3062-3080, 2004.

[3] Ram Ramanathan, Challenges: a radically new architecture for next generation mobile ad hoc networks, International Conference on Mobile Computing and Networking Proceedings of the 11th annual international conference on Mobile computing and networking; Session:Challenge Papers, Pages: 132-139, 2005.

[4] Claude E. Shannon, Two-way Communication Channels, Proc. Fourth Berkeley Symp. On Math. Statist. and Prob., Vol. 1 (Univ. of Calif. Press, 1961), Pages:611-644.

[5] David Tse, Pramod Viswanath, Fundamentals of Wireless Communication, Cambridge University Press, 2005.

[6] Shengli Zhang, Soung Chang Liew, Patrick P.Lam, Hot topic: physical-layer network coding, International Conference on Mobile Computing and Networking Proceedings of the 12th annual international conference on Mobile computing and networking; Session:New Topics, Pages: 358-365, 2006.

[7] Sachin Katti, Hariharan Rahul, Wenjun Hu, Dina Katabi, Muriel Medard and Jon Crowcroft, XORs in the air: practical wireless network coding, ACM SIGCOMM Computer Communication Review, Proceedings of the 2006 conference on Applications, technologies, architectures, and protocols for computer communications Session:Coding, Pages: 243-254, 2006.

THANK YOU