PRESENTED BY SARAH KWAN

NETWORK CODING

PRESENTATION OUTLINE

- What is Network Coding?
- Motivation and Approach
- Network Coding with Lossless Networks
- Challenges in Developing Coding Algorithms + Lossy Networks
- Applications
- Security

NETWORK CODING

- Conventional network architecture: store & forward, duplicate & transmit
- Networking was rooted in wireline technologies, but now new technology has created new services requiring new coding techniques
- "coding at a node in a network as network coding" from "Network information flow" by Ahlswede, et al.
  - With error-free (info theory) or noisy links (channel coding), depending on the area of study
  - Simple concept "Source coding"/Data compression

Data can be seen as a random variable $X : \Omega \to \mathcal{X}$, where $x \in \mathcal{X}$ appears with probability $\mathbb{P}[X = x]$.

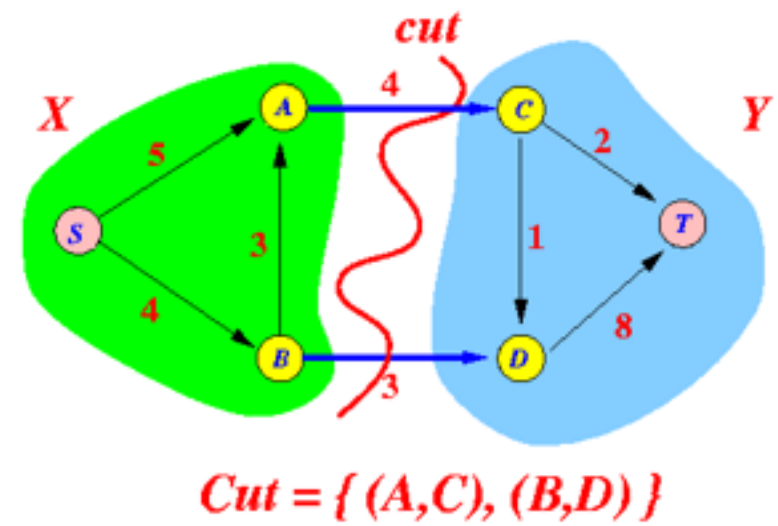
Data are encoded by strings (words) over an alphabet Σ.

A code is a function

$C : \mathcal{X} \to \Sigma^*$ (or Σ^+ if the empty string is not part of the alphabet).

  - Many areas within coding theory, network coding is one of them.

MULTICAST AND UNICAST CODING



- Multicast includes a source with many sink nodes:
    - Central theorem: Transmission rate r is possible between source and sink node, then it is possible to transmit at said rate from source to all sink nodes simultaneously with network coding. Proof is obtained by extending the proof from unicast case.
- Max flow, Min cut theorem of optimization theory: Max flow from a source to a sink equals the sum of the maximum flow in the minimum cut. Cut refers to the edges that connect source to sink.
- Unicast: a simplification of multicast.
    - Central theorem saying that a rate r exists in the transmission between a source and sink node, the transmission rate of the minimum cut between those two nodes is at least r.
- Can extend multicast theorem to apply to several nodes to same set of sink nodes.
    - Can get a lot more technical going into the theorems and proofs that form backbone for network coding theorem.

http://www.mathcs.emory.edu/~cheung/Courses/323/Syllabus/NetFlow/FIGS/netflow09a.gif

NETWORK CODE FORMULATION

- What was described was basics of network coding for lossless networks - wireline networks.
    - One multicast session = all sink nodes will receive same transmission data
- How to develop network code when there exist many sessions? Can allot a subgraph to each session.
    - Subgraph is subnetwork - network divided into a smaller set of nodes. Complications arise with dividing a network into subgraphs.
- From determining how to code for a static network model, techniques can be extended to model dynamic network models
    - packets can follow time-varying routing schedules with different network codes. Goes into packet networking theory.
- To involve more probability and statistics, the activity at source nodes may also be correlated rather than independent.
    - joint-source network coding, random network coding.

SUBGRAPH SELECTION

- Two main approaches to develop network code after subgraphs are formed: centralized polynomial time coding and random (coefficients) linear coding.
- Network resource allocation problem
    - Resource is are the packets (packet sizes, packet send rate)
- Determine routing and scheduling to reach optimality goals for the network and network subgraphs - typical problems of conventional networking
- More networking theory than information and coding theory:
    - To arrive at optimality goals, network could utilize intersession networking, in which network code involves more than one session- complexity increases.

INTERSESSION NETWORKING

- For multiple sessions, linear network coding does not account for all complexity that is involved to arrive at optimal parameters - nonlinear problem.
- More information theory
  - Entropy, joint conditional entropies, Shannon type information inequalities, "matroids"
- Constructive Approaches:
  - Intersession Networking is so complex that suboptimal but simplified approaches to construct code are practical and often suitable for implementing in networks.

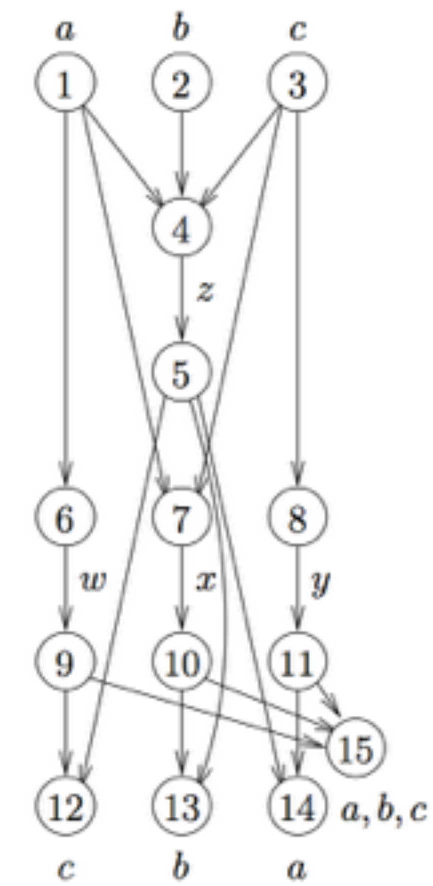


Fig. 3.6. A network associated with the non-Fano matroid. Source processes a, b, c originate at nodes 1,2,3 respectively, and are demanded by the sets of sink nodes $\{14, 15\}, \{13, 15\}, \{12, 15\}$ respectively. The source and edge labels indicate the correspondence with the elements of the non-Fano matroid as shown in Figure 3.5. The network has no vector linear solution of any dimension over a finite field with characteristic 2.

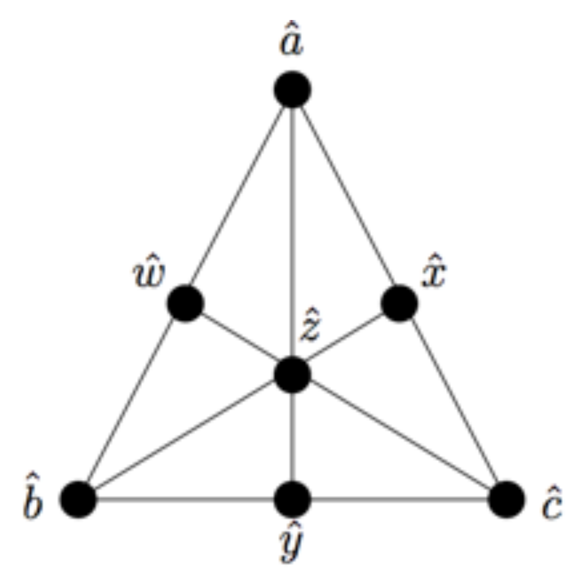


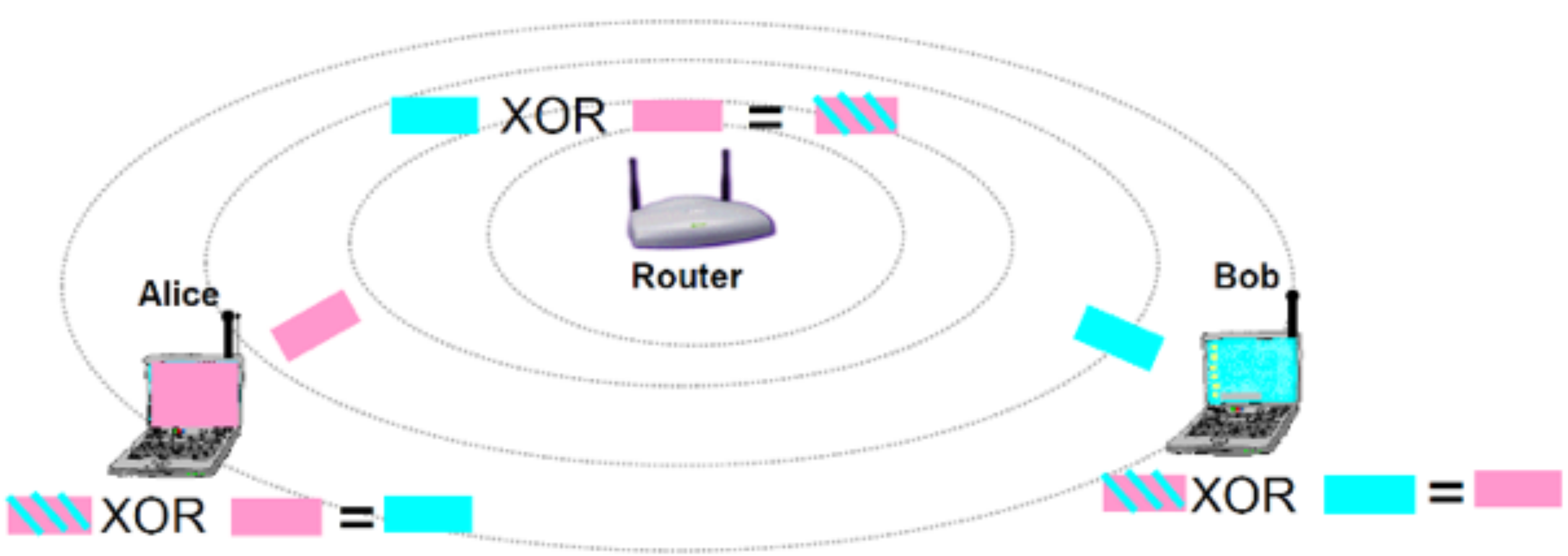
Fig. 3.5. A geometric representation of the non-Fano matroid. The labeled dots correspond to the elements of the underlying set, any three elements of which are dependent if and only if in the diagram they are collinear.

BITWISE CODING AND LOSSY NETWORKS

- Wireline Networks
  - Bitwise XOR coding: packets from different sessions are XOR-ed bit by bit in some fashion: found to have increase throughput for both sessions by an amount specific to the coding scheme
- Wireless Networks
  - May have more aspects in network performance improvement than in wireline mediums due to properties of wireless medium
    - ie. Wireless networks include scenarios bidirectional data transfers are possible in wireless medium, Simultaneous transmissions of coded and noncoded packets
  - Interesting scheduling and transmit problems to optimize by way of network codes

CONSIDERATIONS IN ROUTING & CODING

- “Coding-Influenced Routing”
  - Routes can be configured to direct packets to nodes for optimal coding
- “Opportunistic coding”
  - nodes run selective packets on selective codes when they have the opportunity to transmit, could be based on some information, ie. the next hop node and what that next node is able to decode/ encode -> may requires nodes to have information about the coding or packet-queueing schemes of its neighbors
- Because of complexity in problems, contraints have to be placed on parameters
  - Number of sessions from which packets that will be “mixed”, the techniques for designing a coding algorithm, data transfer and path-intersection scenarios, etc.



RELATED RESEARCH

- Popular area of research to develop algorithms
- Many variations of XOR Bitwise codes have been worked on published in research papers:
    - Opportunistic Multihop Routing [2]:
        - Source first learns which nodes received a sent transmission, then decides which is next hop node, code based on acknowledgements
    - Embracing Wireless Interference: Analog Network Coding [3]:
        - Mixing signals rather than bits and allowing for nodes to apply known network information to cancel out interference. The advantage? Increase throughput.
    - Randomness in Wireless Opportunistic Routing [4]:
        - Randomly mixing packets to solve for the issue that strict bitwise coding that is dependent on MAC on packets prevents spatial reuse due to some properties of 802.11 MAC
    - XORs Codes of Wireless nodes [5] :
        - Codes based on network conditions like traffic patterns, congestion level, transport protocol

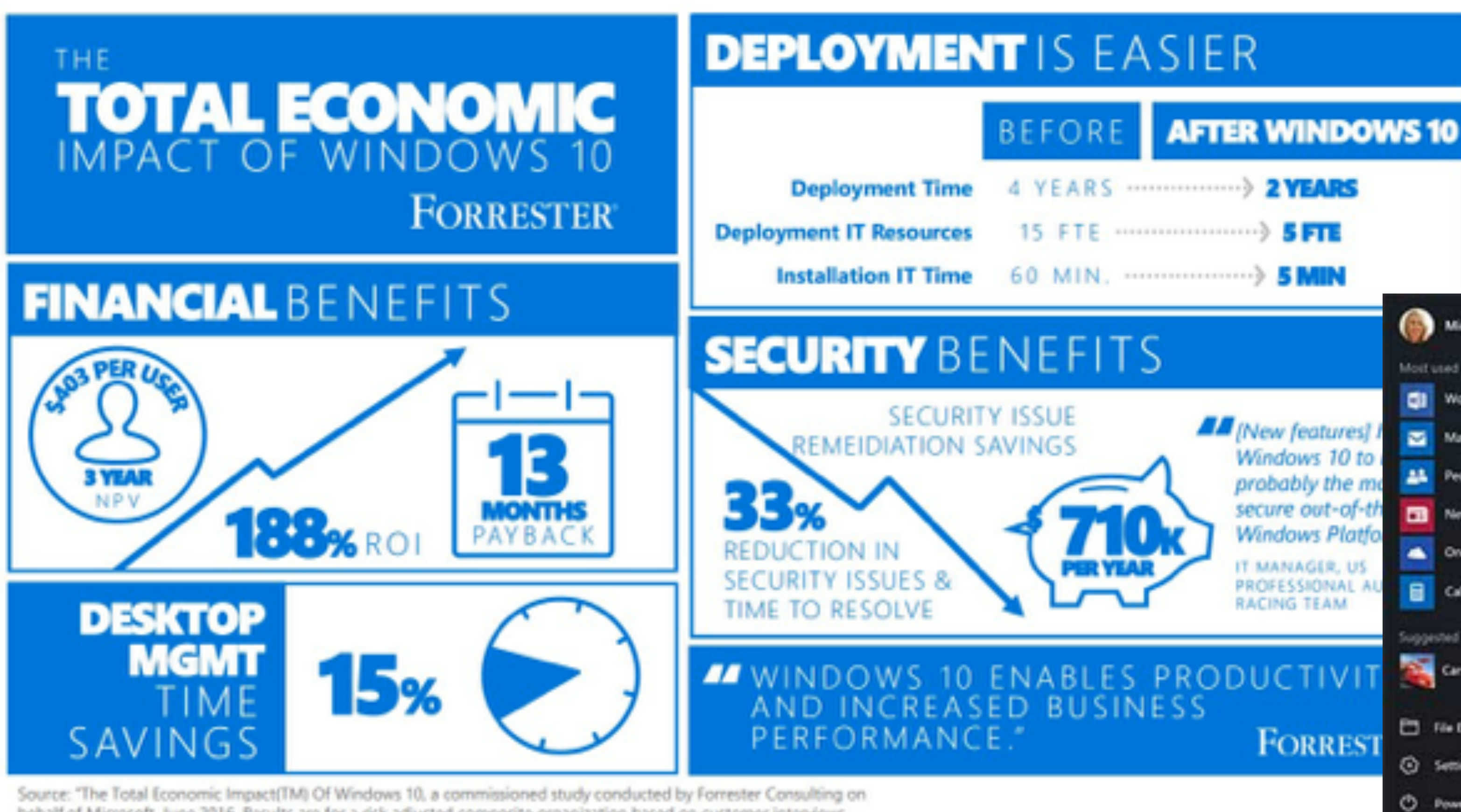
MORE ON LOSSY NETWORKS

- Network with high “lossiness”
    - Packet erasure is high, usually caused by high joining and leaving of transient nodes.
- One solution employs random linear network coding to achieve high packet reception rate intervals (quantified as: packets received per time interval).
    - In a gist: packets stored in node memory, and in order to transmit, randomization is done on the packets stored in the node to create the final packet that is transmitted out
- By applying further heuristics, there can be increased probability of the receiving nodes receiving packets that they are meant to receive, aka. are able to also decode or decrypt.
- A lot more theory on coding for lossy networks
    - Coding theorems: unicast vs. multicast connection
    - Error exponents for Poisson traffic

APPLICATIONS OF NETWORK CODING

as per wikipedia:

- Alternative to forward error correction and ARQ in traditional and wireless networks with packet loss. e.g.: Coded TCP,[8] Multi-user ARQ[9]
- Robust and resilient to network attacks like snooping, eavesdropping, replay or data corruption attacks.[10][11]
- Digital file distribution and P2P file sharing. e.g.: Avalanche from Microsoft



http://i1-news.softpedia-static.com/images/news2/microsoft-expecting-avalanche-for-windows-10-upgrades-in-next-months-506268-2.jpg

https://dri1.img.digitalrivercontent.net/Storefront/Company/msintl/images/English/en-INTL-Windows-10-Home-KW9-00265/en-INTL-L-Windows-10-Home-KW9-00265-RM2-mnco.jpg

MORE APPLICATIONS

as per wikipedia:

- Distributed storage.[12][13]
- Throughput increase in wireless mesh networks. e.g. : COPE,[14] CORE,[15] Coding-aware routing,[16][17] B.A.T.M.A.N.[18]
- Bidirectional low energy transmission in wireless sensor networks.
- Many-to-many broadcast network capacity augmentations.
- Buffer and Delay reduction in spatial sensor networks: Spatial buffer multiplexing [19]
- Reduce the number of packet retransmission for a single-hop wireless multicast transmission, and hence improve network bandwidth.[20]
- Distributed file sharing [21]

SECURITY AGAINST ADVERSARIAL BEHAVIOR

- Adversaries might sniff the network or have some control over some branches in network.
- Intermediate nodes may not be secure.
- Employ error correction codes
  - Correct for errors introduced in the channels or by nodes to maintain integrity of packets even in a potentially insecure network.
- Detection of Adversarial Packets
  - Use random coding coefficients and maybe hash symbols combined with error detection schemes
  - High probability to detect a packet with an error
  - Based off premise that adversary does not know the entirety of the coding scheme of random network code

BIBLIOGRAPHY

Biswas, Sanjit, and Robert Morris. "ExOR: Opportunistic Multi-Hop Routing for Wireless Networks." ACM SIGCOMM Computer Communication Review 35.4 (2005): 133. Web.

Chachulski, Szymon, Michael Jennings, Sachin Katti, and Dina Katabi. "Trading Structure for Randomness in Wireless Opportunistic Routing." Proceedings of the 2007 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications - SIGCOMM '07 (2007): n. pag. Web.

Ho, Tracey, and Desmond Lun. Network Coding an Introduction. Cambridge: Cambridge UP, 2008. Web.

Katti, Sachin, Hariharan Rahul, Wenjun Hu, Dina Katabi, Muriel Médard, and Jon Crowcroft. "XORs in the Air: Practical Wireless Network Coding." XORs in the Air: Practical Wireless Network Coding (n.d.): n. pag. Web.

Katti, Sachin, Shyamnath Gollakota, and Dina Katabi. "Embracing Wireless Interference." ACM SIGCOMM Computer Communication Review 37.4 (2007): 397. Web.

Sundararajan, Jay Kumar, Devavrat Shah, Muriel Médard, Szymon Jakubczak, Michael Mitzenmacher, and João Barros. "Network Coding Meets TCP: Theory and Implementation." Proceedings of the IEEE 99.3 (2011): 490-512. Web.