Transcoding: A New Strategy for Relay Channels

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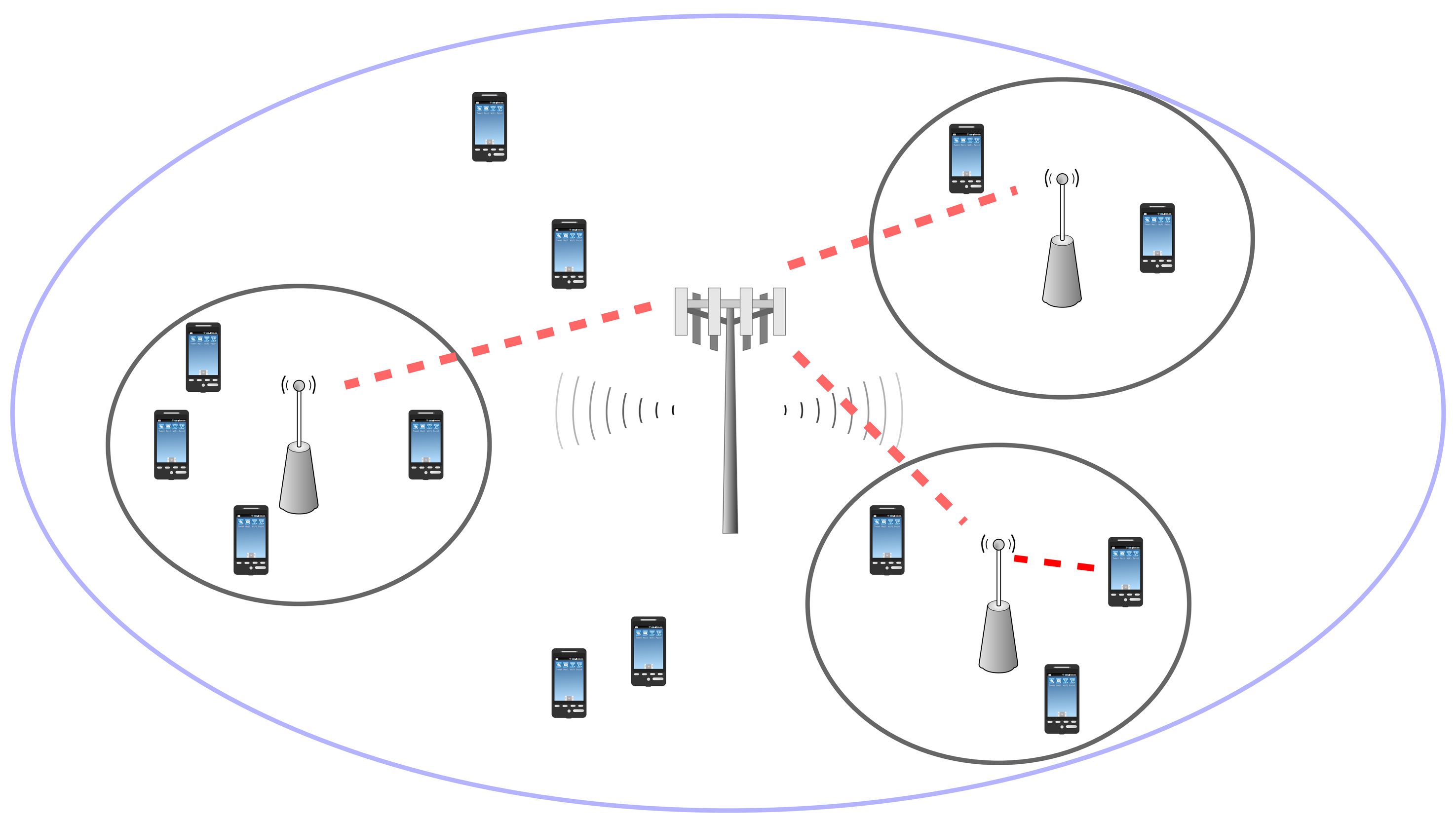
Rise of Multi-hop, Low-latency Communication

- Number of wireless devices continues to grow
- Many "new" devices will be low-power Internet of Things (IoT) devices
- Potentially **no direct connection to base station**
- Cellular: Move to **small cell networks**, in-band wireless (self-)backhauling

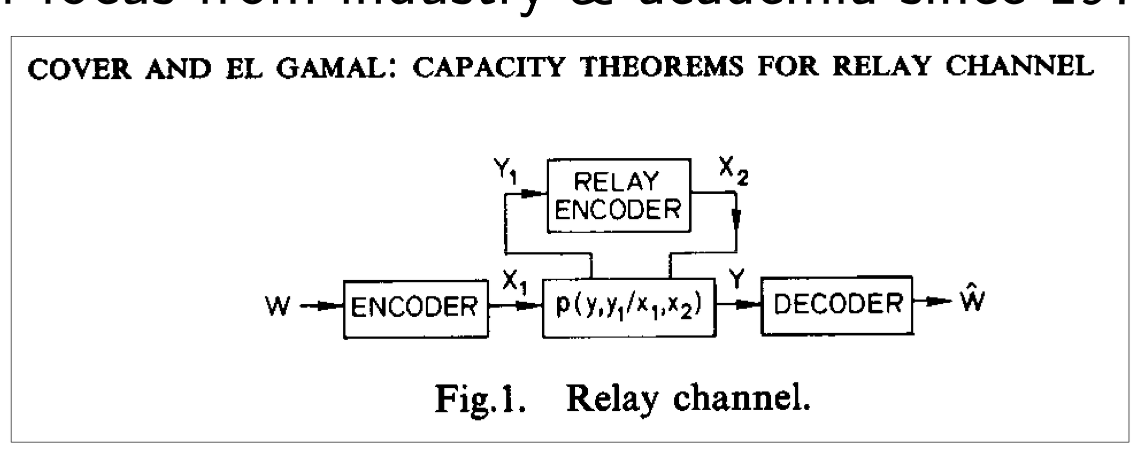


Small cell network with wireless backhaul

- Additionally: Growing focus on **low latency**
- Sub-1ms latency in IMT-2020

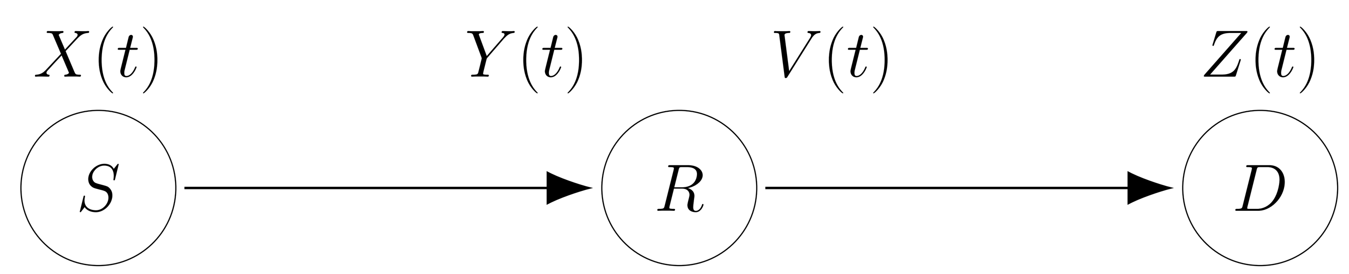
The Relay Channel: A Classic Problem in Information Theory

- Lots of focus from industry & academia since 1970s



- Many different design philosophies: Compress-&-Forward [1], Hash-&-Forward [2], Compute-&-Forward [3], Noisy Network Coding [4]
- De-facto industry standard: Decode-&-Forward (DF) [1]
- **Traditional schemes focus on capacity rather than delay performance** ($\Rightarrow$ long block lengths)
- Our interest: Low latency, short, **finite block lengths**
- Amplify-&-Forward (AF) gives best delay performance but suffers throughput loss due to noise build-up

Separated Two-hop Relay Channel

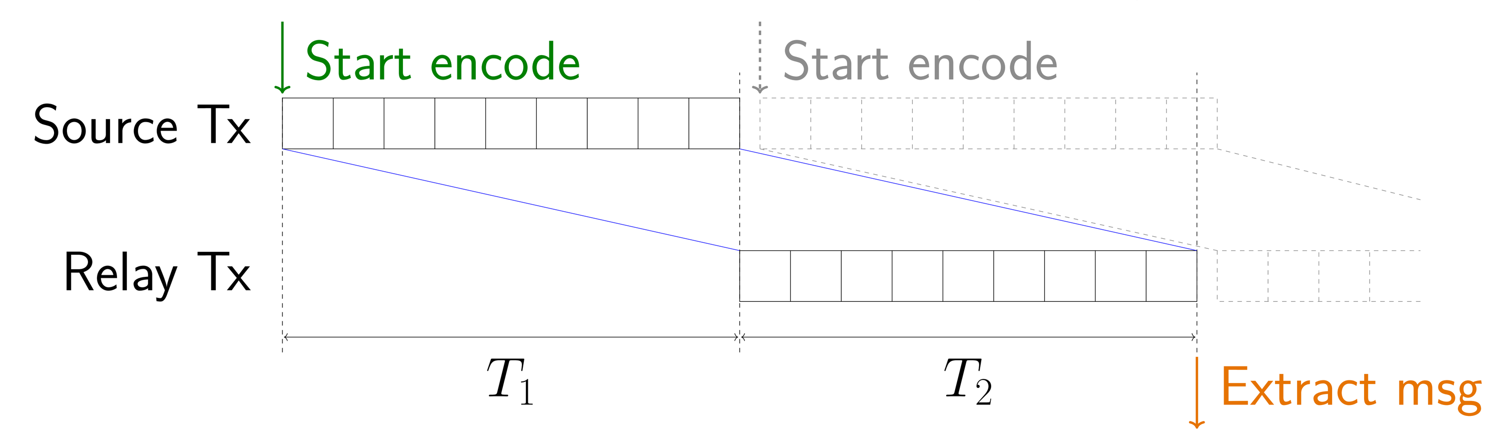


- No connection between source and destination
- "Degraded" relay channel, DF achieves capacity (with infinite delay)

Decode-&-Forward

- Error control through **coding at source and relay**
- End-to-end delay: $T = T_1 + T_2$
- Pipelined coding rate:

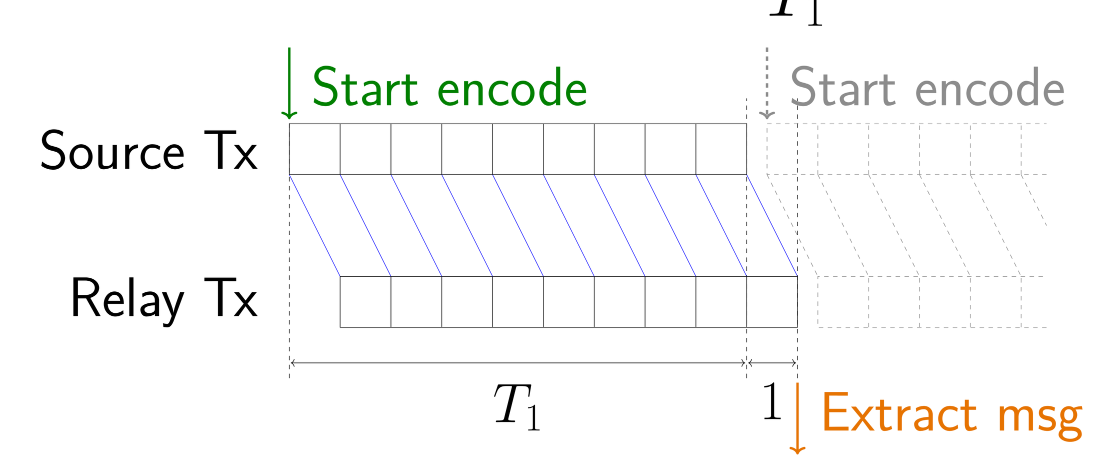
$$R_{DF}(T, \epsilon) = \frac{\log M}{\max(T_1, T_2)}$$



Amplify-&-Forward

- No error correction at relay $\Rightarrow$ **noise accumulation**
- End-to-end delay: $T = T_1 + 1$
- Pipelined coding rate:

$$R_{AF}(T, \epsilon) = \frac{\log M}{T_1}$$



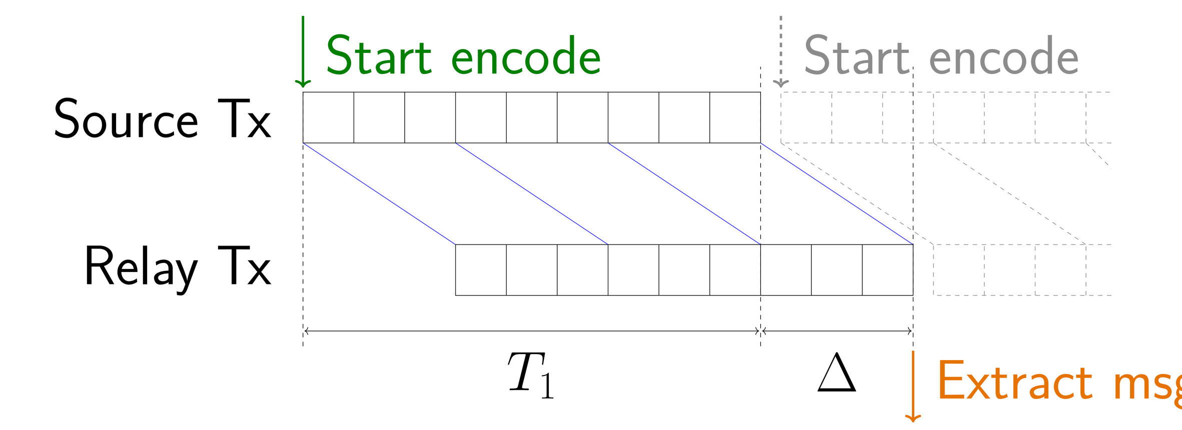
Transcoding as "middle ground" between AF and DF

- Can be viewed as "smart" AF with error protection
- Improved coding rate in low latency regime

Transcoding

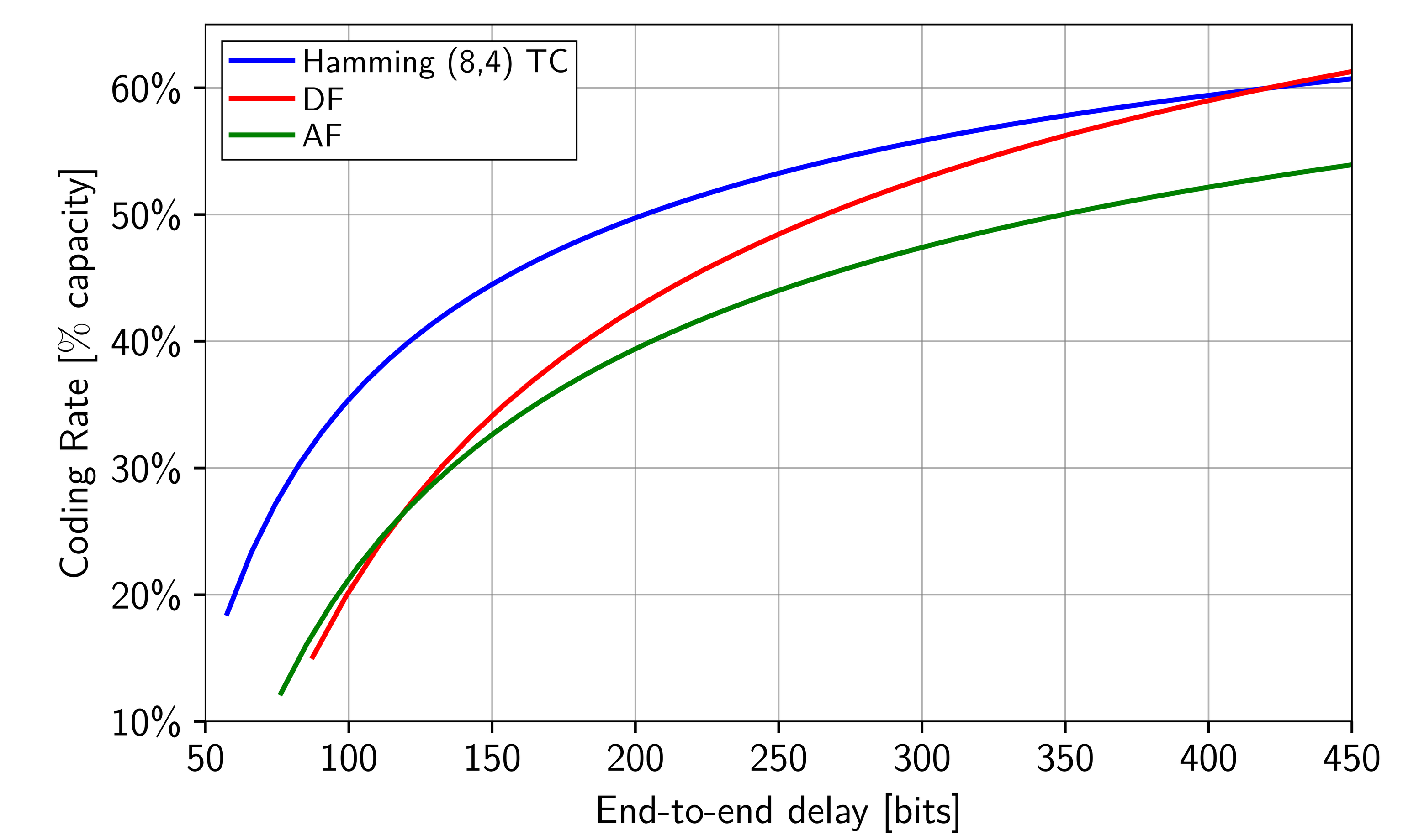
- Idea: Relay processes sub-blocks of size Δ
- Structure in sub-blocks $\Rightarrow$ **Error control at relay**
- End-to-end delay: $T = T_1 + \Delta$
- Pipelined coding rate:

$$R_{TC}(T, \epsilon) = \frac{\log M}{T_1}$$



Example: $\Delta = 8$ [5]

- Binary symmetric channel on both hops
- Take sub-blocks from (8,4) extended Hamming Code
- Parameters: $p_1 = 0.04$, $p_2 = 0.13$, $\epsilon = 10^{-3}$
- Normal approximation [6] to evaluate rate-delay tradeoff



Ongoing Work

- Random code construction & analysis
- General transcoder design theory
- Extension to multi-hop & fading channels

[1] T. Cover and A. E. Gamal, "Capacity theorems for the relay channel," *IEEE Trans. Inform. Theory*, vol. 25, no. 5, pp. 572–584, Sep. 1979, ISSN: 0018-9448.

[2] T. M. Cover and Y. H. Kim, "Capacity of a class of deterministic relay channels," in *2007 IEEE International Symposium on Information Theory*, Jun. 2007, pp. 591–595.

[3] B. Nazer and M. Gastpar, "Compute-and-forward: Harnessing interference through structured codes," *IEEE Trans. Inform. Theory*, vol. 57, no. 10, pp. 6463–6486, Oct. 2011, ISSN: 0018-9448.

[4] S. H. Lim, Y. H. Kim, A. E. Gamal, and S. Y. Chung, "Noisy network coding," *IEEE Transactions on Information Theory*, vol. 57, no. 5, pp. 3132–3152, May 2011, ISSN: 0018-9448.

[5] C. C. Wang, D. J. Love, and D. Ogbe, "Transcoding: A new strategy for relay channels," in *2017 55th Annual Allerton Conference on Communication, Control, and Computing (Allerton)*, Oct. 2017, pp. 450–454.

[6] Y. Polyanskiy, H. V. Poor, and S. Verdu, "Channel coding rate in the finite blocklength regime," *IEEE Trans. Inform. Theory*, vol. 56, no. 5, pp. 2307–2359, May 2010, ISSN: 0018-9448.

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