Coding for Super Dense Networks [1]

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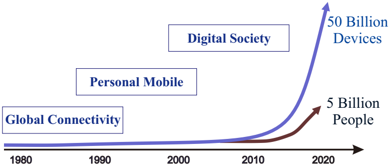
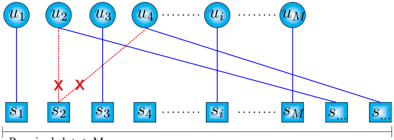
- **Problem 1**: Billions connected devices in 2020[2], forming *super dense networks*.
- **Problem 2**: High complexity of fixed transmission scheduling in multiway relay systems.
- **Problem 3**: Low throughput of random access technology.
- Prospective applications: disaster areas networks, wireless sensor networks, high density areas networks, satellite communications.



(a) Billions connected devices in 2020



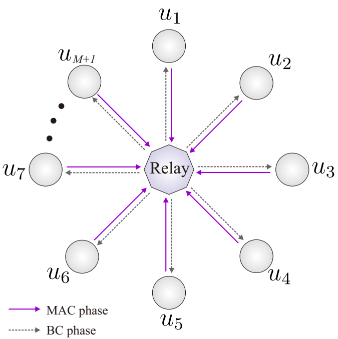
(b) Low throughput of random access

Objective

Design uncordinated multiway relay networks serving *massive* number of users and having high throughput attained by employing multiuser detection.

[2] Ericsson, *More Than 50 Billion Connected Devices*, Ericsson White Paper, February, 2011.

System Model



- All users want to exchange information among themselves with the relay's help.
- Relay: Amplify-and-Forward, Half-Duplex.
- Synchronous (slot) transmission.
- Transmission phases: Multiple Access Channel (MAC) and Broadcast Channel (BC).
- *Pair-of-Time-Slot* (PTS): a MAC phase followed by a BC phase.
- 1 contention period is composed of N PTSs.
- Offered traffic (logical) load delivered to **one user** :

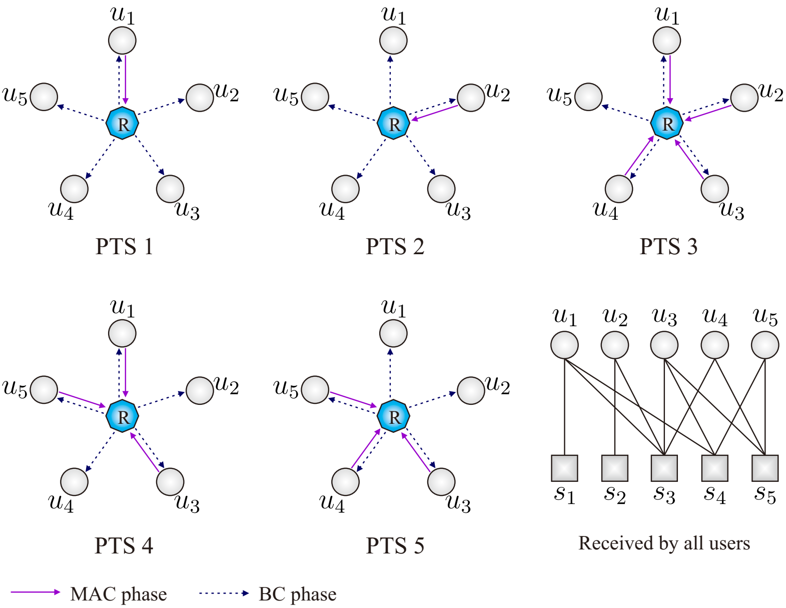
$$G = \frac{M}{N}. \tag{1}$$

- The users randomly select the code type $c_h \sim (h, 1)$ according to the given probability mass function (*pmf*)

$$\Lambda = \{\Lambda_2, \Lambda_3, ..., \Lambda_n\}$$

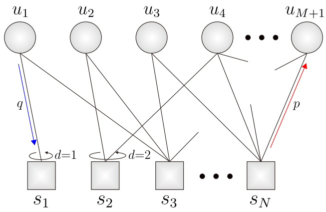
- Code $c_h \sim (h, 1)$ is *packet-oriented* repetition coded with order h.
- Networks Rate per user: $R_N = \frac{1}{\sum \Lambda_h h} = \frac{1}{\overline{n}}$, where $\overline{n}$ is the expected length of the code.

Transmission Scheme - Networks



Decoding & Asymptotic Analysis

- Find s node with degree d=1, then do:
  - Local Decoding in s node and then u node.
  - SIC in the connected s nodes.
- If no s node with d=1, find s node with d=2, then do :
  - Local decoding in s node using iterative demapping (IDM)[3] algorithm to decode two users messages.
  - Local decoding in u nodes.
  - SIC in the connected s nodes.
- Stop if all information are decoded or max iteration.



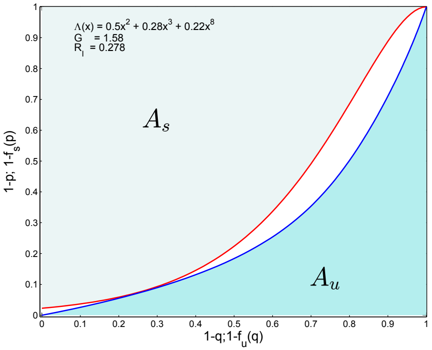
Asymptotic Analysis

- Degree distribution of u nodes is $\lambda(x) = \sum_{h=2}^{n} \lambda_h x^{h-1}$
- Degree distribution of s nodes is $\rho(x) = \exp\left(-\frac{\overline{n}}{G}(1-x)\right)$
- The erasure probability from u nodes to s nodes, and from s nodes to u nodes, respectively:

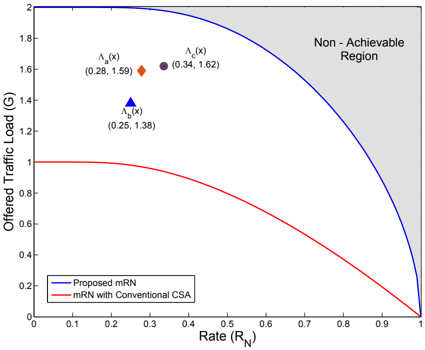
$$q = \sum_{h=2}^{n} \lambda_h p^{h-1} := f_u(p) \tag{2}$$

$$p = 1 - \left(1 + q\frac{G}{R_N}\right) e^{-q\frac{G}{R_N}} := f_s(q) \tag{3}$$

[3] Anwar, K. and Matsumoto, T., Three-way relaying systems using iterative spatial demapping, ISTC, Aug. 2012



(a) EXIT Chart

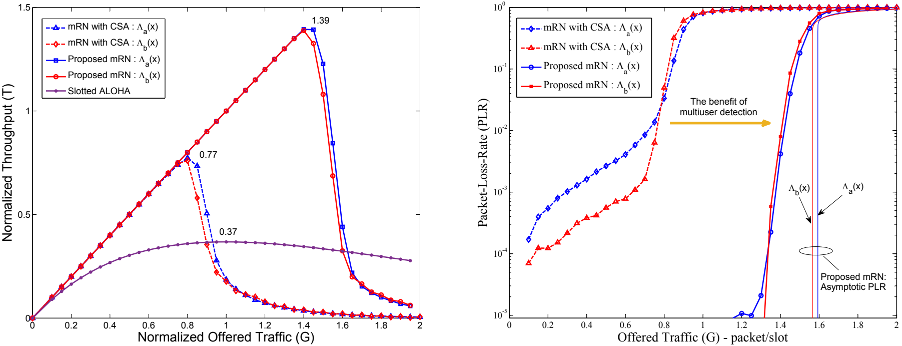


(b) Upper Bound

- The evolution of $f_u(p)$ and $f_s(q)$ are plotted into the EXIT chart to characterize the convergence behavior of decoding process.
- Threshold value G^* is defined as the maximum value of G such that there is open tunnel between two curves.
- The upper bound of the system derived from EXIT chart area theorem is given by

$$R_N + \left(1 + \frac{2R_N}{G}\right) e^{-G/R_N} - \frac{2R_N}{G} < 0, \tag{4}$$

Simulation Results - Throughput & PLR



- Simulation parameters :
  - $N = 200$ PTSs
  - M is variable depends on G
  - $\Lambda_a(x) = 0.5x^2 + 0.28x^3 + 0.22x^8$
  - $\Lambda_b(x) = 0.25x^2 + 0.6x^3 + 0.15x^8$
- The proposed systems achieve throughput of more than 1 packet/slot and very low PLR.

Conclusions

1. We have proposed uncoordinated multiway relaying systems that can serve massive number of users.

2. Employment of IDM as the multiuser detector increases the throughput of the systems significantly. It make possible to utilize number of slots less than number of users.

3. The proposed systems can be optimized by choosing a proper degree distribution of u nodes such that G^* close to the bound.