Energy Efficient Random Multiple Access with Strict Delay Constraints

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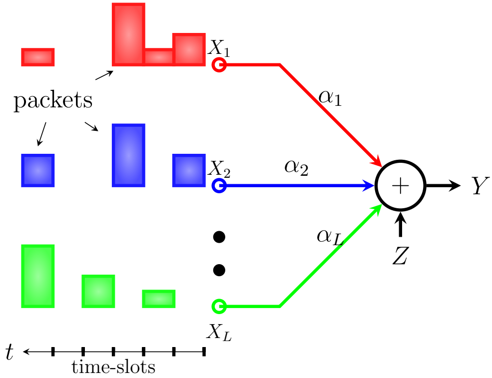
Distributed Multiple Access



El Gamal et al, " Energy efficient scheduling of packet transmissions over wireless networks", INFOCOM 2002.

1)Is it possible?

2)What is the cost?

Flush packets without *delay* + *high success-rate* using distributed info.

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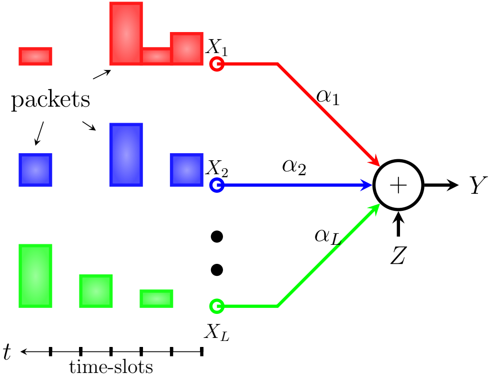

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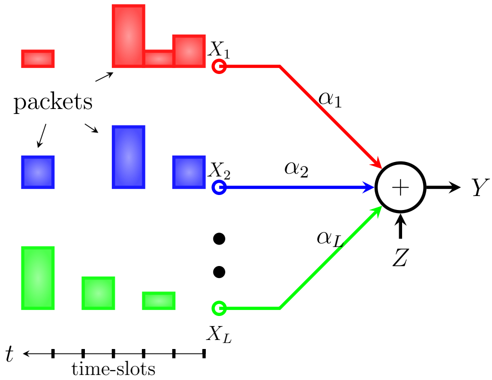

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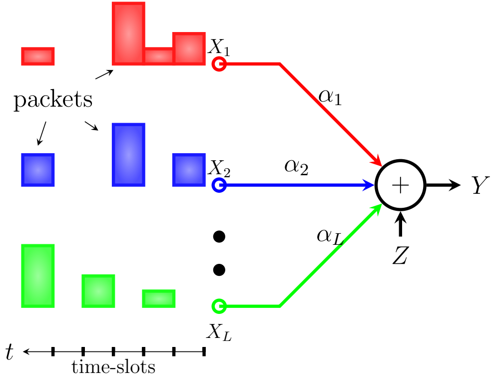

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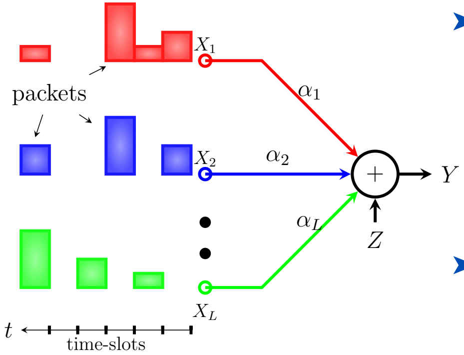
Time Division Multiple Access



- Assume $\alpha_i = \alpha, \forall i$.
- User i requires rate $B_i \in \mathcal{B}$,

$$\frac{1}{L} \cdot \frac{1}{2} \log(1 + L\alpha^2 P_i) = B_i$$

- The required power is

$$P_i(B_i) = \frac{2^{2LB_i} - 1}{\alpha^2}$$

Uncoordinated Access

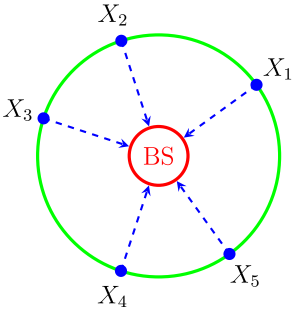


Figure: Symmetric MAC

- User i employs a rate B_i codebook of blocklength n and average power

$$P_i(B_i) = \frac{2^{2LB_i} - 1}{\alpha^2}$$

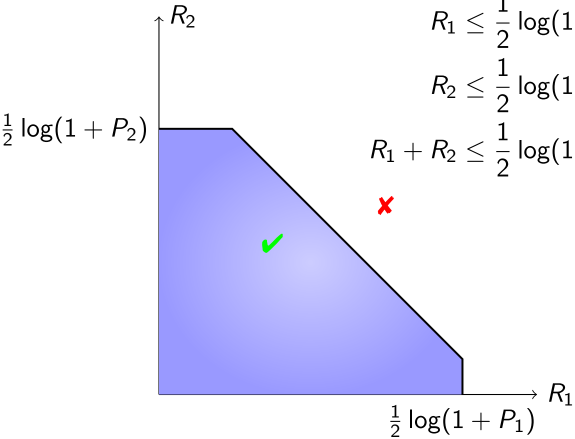
- Transmissions interfere with each other.
- Can we still decode everyone?

Two User Capacity Region $C_{MAC}(P_1, P_2)$

$$R_1 \leq \frac{1}{2}\log(1+P_1)$$

$$R_2 \leq \frac{1}{2}\log(1+P_2)$$

$$R_1 + R_2 \leq \frac{1}{2}\log(1+P_1+P_2)$$



The region also includes TDMA rates, i.e. our power choice works!

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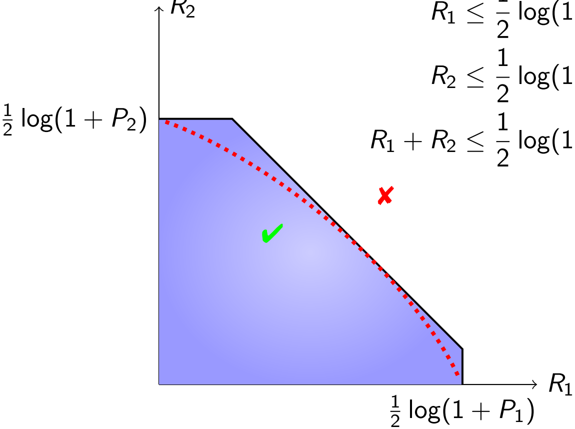

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Optimality

Lemma

With identical link gains and arrival statistics

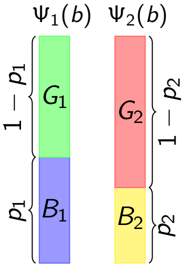
$$P_{sum}^{min} = \frac{1}{\alpha^2}\mathbb{E}[2^{2LB} - 1].$$

Proof.

$$\begin{aligned}
\mathbb{E}\sum_{i=1}^{L} P_i(B_i) &= \mathbb{E}\sum_{i=1}^{L} P_i(B) \\
&= \frac{1}{\alpha^2}\mathbb{E}\left(2^{\log(1+\alpha^2\sum_{i=1}^{L} P_i(B))} - 1\right) \\
&\geq \frac{1}{\alpha^2}\mathbb{E}\left(2^{2LB} - 1\right).
\end{aligned}$$

□

Non-identical Arrival Statistics



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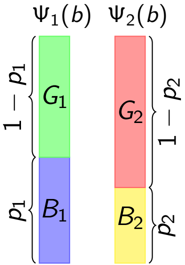

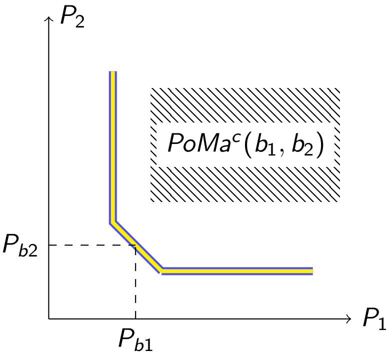

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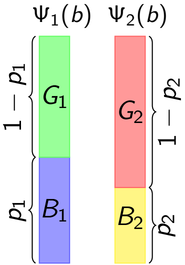

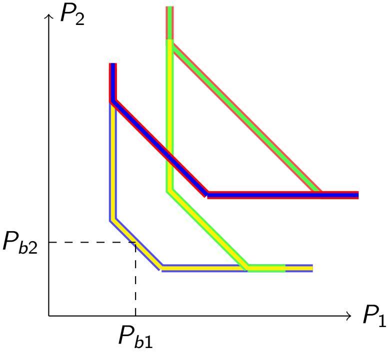

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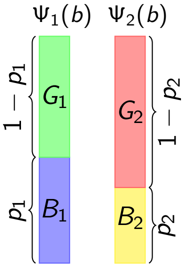

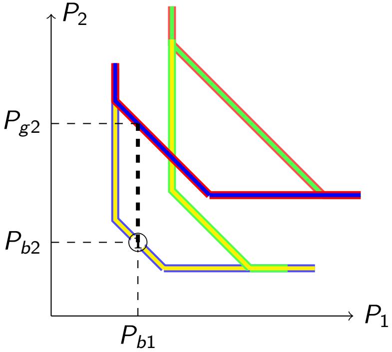

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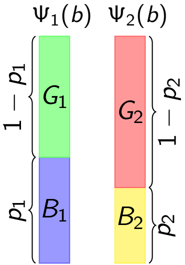

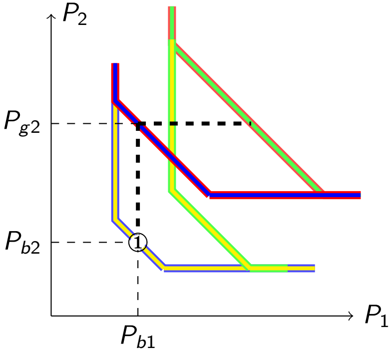

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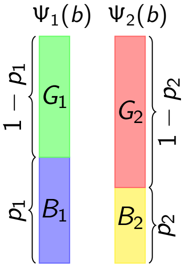

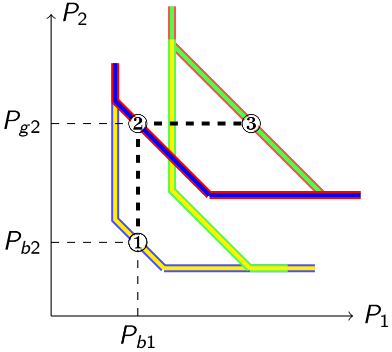

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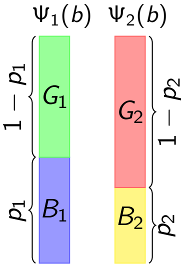

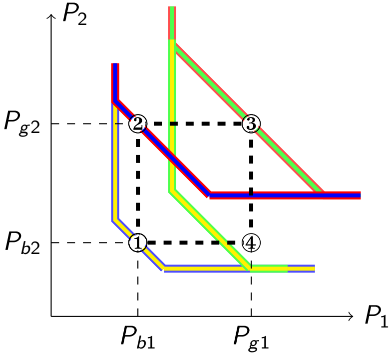

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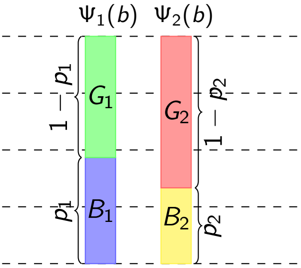

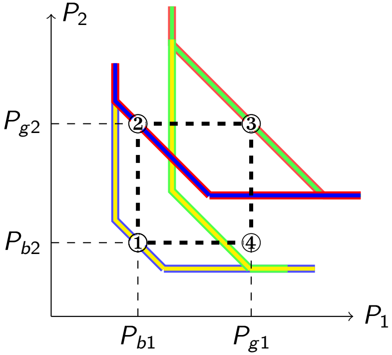

- Allocation not only **successful**, but also **Power Optimal** for

$$\min \sum_{i=1}^{L} \mathbb{E} P_i(B_i) : (P_i(B_i), P_j(B_j)) \in PoMa^c(B_i, B_j) \forall i, j.$$

- *S. Sreekumar, SRBP, B. K. Dey, On the adaptive sum-capacity of MAC with distributed CSI and non-indentical links, ISIT 2013*

Non-identical Arrivals

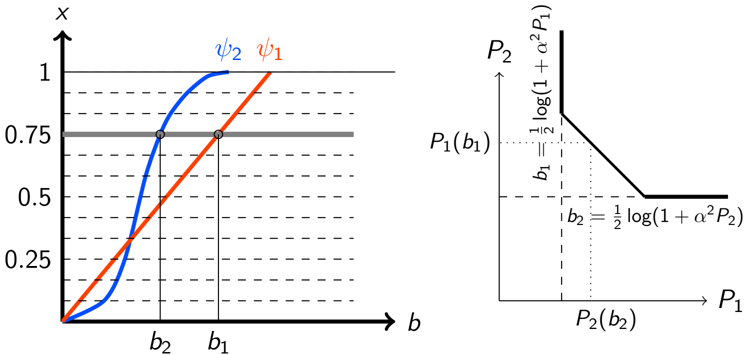

Figure: Optimal Sum-power Allocation

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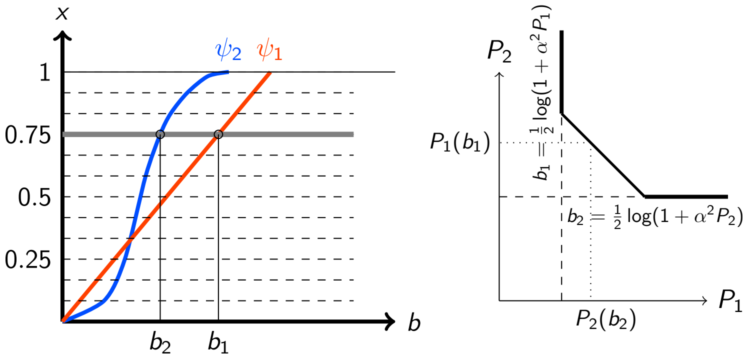
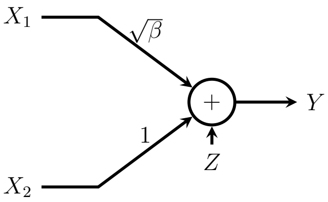


Figure: Optimal Sum-power Allocation

$$P_{sum}^{min} = \int_0^1 \frac{2^{2(b_1(x)+b_2(x))} - 1}{\alpha^2} dx, \text{ where } b_i(x) = sup\{b \mid \Psi_i(b) \leq x\}.$$

Asymmetric Links



- To support a packet-rate pair of (b_1, b_2),

$$\beta P_1(b_1) + P_2(b_2) \geq 2^{2(b_1+b_2)} - 1$$

- **Difficulty:** This does not parse into a suitable constraint on $P_1 + P_2$.

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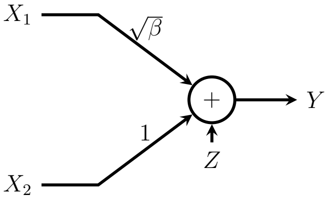

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CDF Transformations

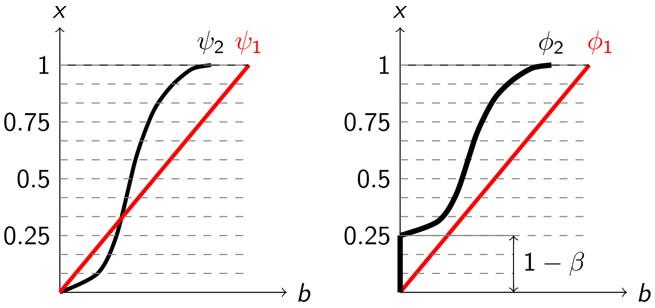

Figure: Optimal Power-allocation for $\beta = 0.75$

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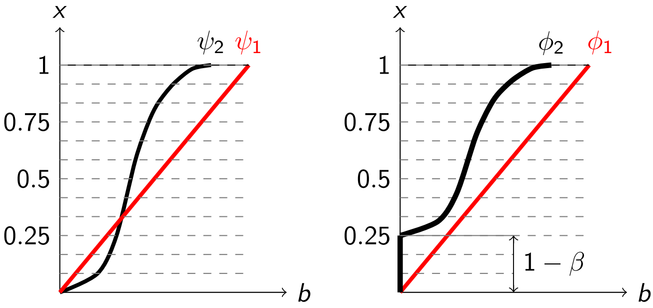

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Theorem

The minimum sum-power for our MAC model is

$$P_{sum}^{min} = \int_0^{1-\beta} \frac{2^{2b_1(x)} - 1}{\beta} dx + \int_0^{\beta} \frac{2^{2(b_1(v+1-\beta)+b_2(\frac{v}{\beta}))} - 1}{\beta} dv$$

Power-Savings

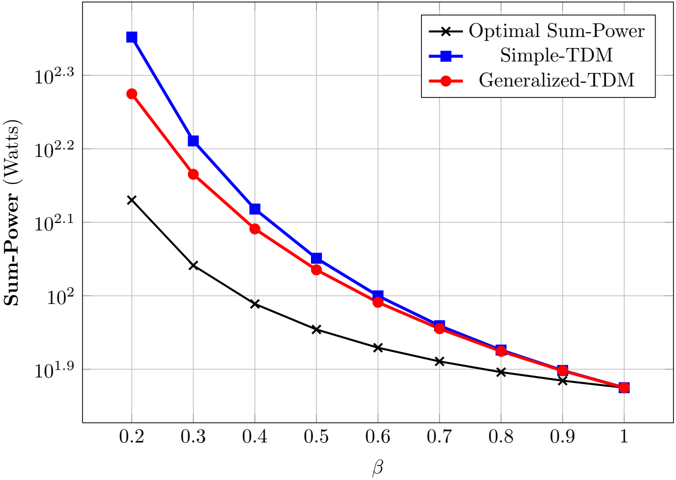

Figure: Power savings for rates in $\{1, 2\}$ with $p(1) = 0.75, \alpha_1 = \beta, \alpha_2 = 1$

Conclusion

- Optimal power allocations under strict delay constraints were proposed for a MAC with random arrivals.
- The approach can also solve the weighted power minimization problem.
- General arrival processes and relaxed delay constraints is a possible future extension.
- A dual result can solve the so called *adaptive capacity region* of distributed CSI MACs Chapter 23 of El Gamal and Kim, Network Information Theory, Cambridge 2011.

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