# SIC under Space-Time Regulation in Random Wireless Networks

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## Context

The growth of IoT and the move toward 5G/6G technology highlights the importance of **ultra-Reliable low Communication (uRLLC) networks** critical for applications. Efficient interference management is key to ensure minimal latency and the reliability of a **multi-user wireless network**. The objective of this work is to quantify the **decoding delays** within random wireless networks that have bounding conditions on the number of users in space, and the number of messages in time. We want to check if the **decoding delay outage probability** can be bounded by a given threshold $\delta > 0$

$$\mathbb{P}(W > d) \leq \delta$$

decoding delay — deadline — delay outage probability threshold

## Time regulation

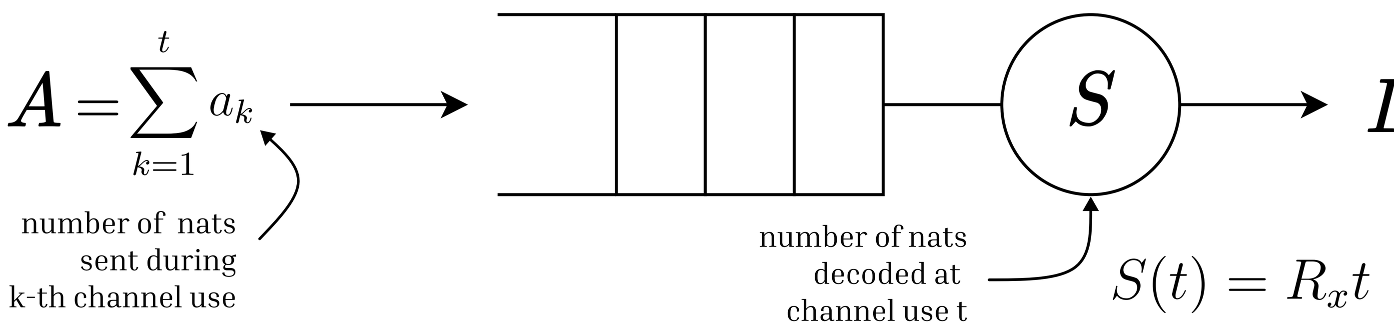
We use the approach introduced in [1]. Suppose

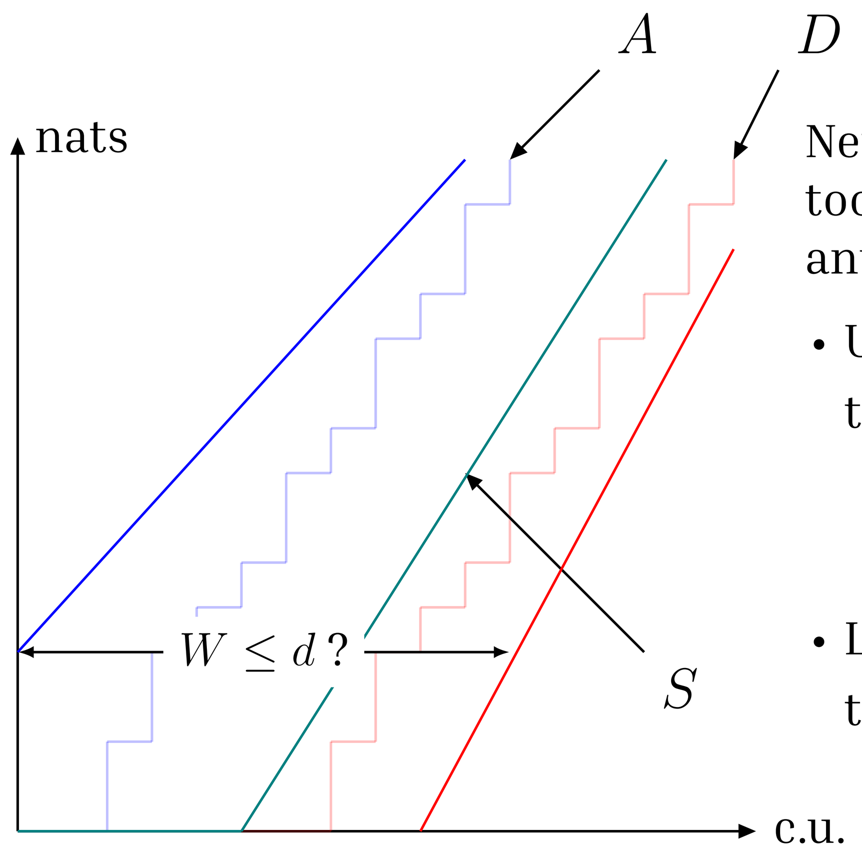
- Successive Interference Cancellation (SIC)
- Per-user received power $P_x$
- Noise density $N_0$

For user $x$, the BS **information decoding power** (with AWGN) is

$$R_x = \ln\left(1 + \frac{P_x}{\sum_{\substack{y\in\Phi \\ P_y < P_x}} P_y + N_0}\right)$$

which provides a decoding speed that we consider as the service that the BS is able to provide to users. Thus the arrival process $A$ enters the network and leaves with respect to the departure process $D$, at a speed given by the service process $S$.




Network calculus [2] provides the tools for deterministic timing guarantees:

- Upper-bound the arrival distribution:

$$\mathbb{E}\left[e^{\theta A(t)}\right] \leq e^{\theta(\sigma_a(\theta)+\rho_a(\theta)t)}$$

- Lower-bound the service distribution:

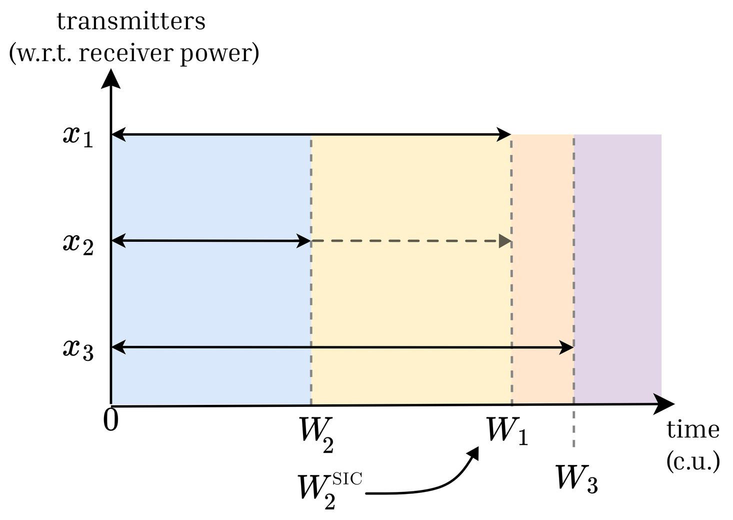
$$\mathbb{E}\left[e^{-\theta S(t)}\right] \leq e^{\theta(\sigma_s(\theta)-\rho_s(\theta)t)}$$

- The departure process is

$$D(t) = \inf_{u \leq t} A(t-u) + S(u)$$

- If $\rho_a(\theta) < \rho_s(\theta)$, the **virtual delay** $W$ is such that

$$\mathbb{P}(W > d) \leq \frac{e^{\theta(\sigma_a(\theta)+\sigma_s(\theta)+\rho_a(\theta)-\rho_s(\theta)d)}}{1 - e^{-\theta(\rho_s(\theta)-\rho_a(\theta))}}$$




With SIC, the decoding delay is the maximum virtual delay over the set of users with more received power $\mathcal{B}_x$

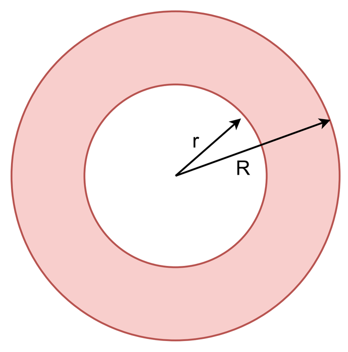
$$W_x^{\mathrm{SIC}} = \max\left(W_x, \max\left(W_y, y \in \mathcal{B}_x\right)\right)$$

## Space regulation

Let $\Phi$ be a stationary marked point process with

$$\Phi(r) = \sum_{\|x\|<r} \delta_{(x,h_x)}$$

where $x$ is the location of users and $h_x$ their (i.i.d. w.r.t. $x$) fading coefficient.



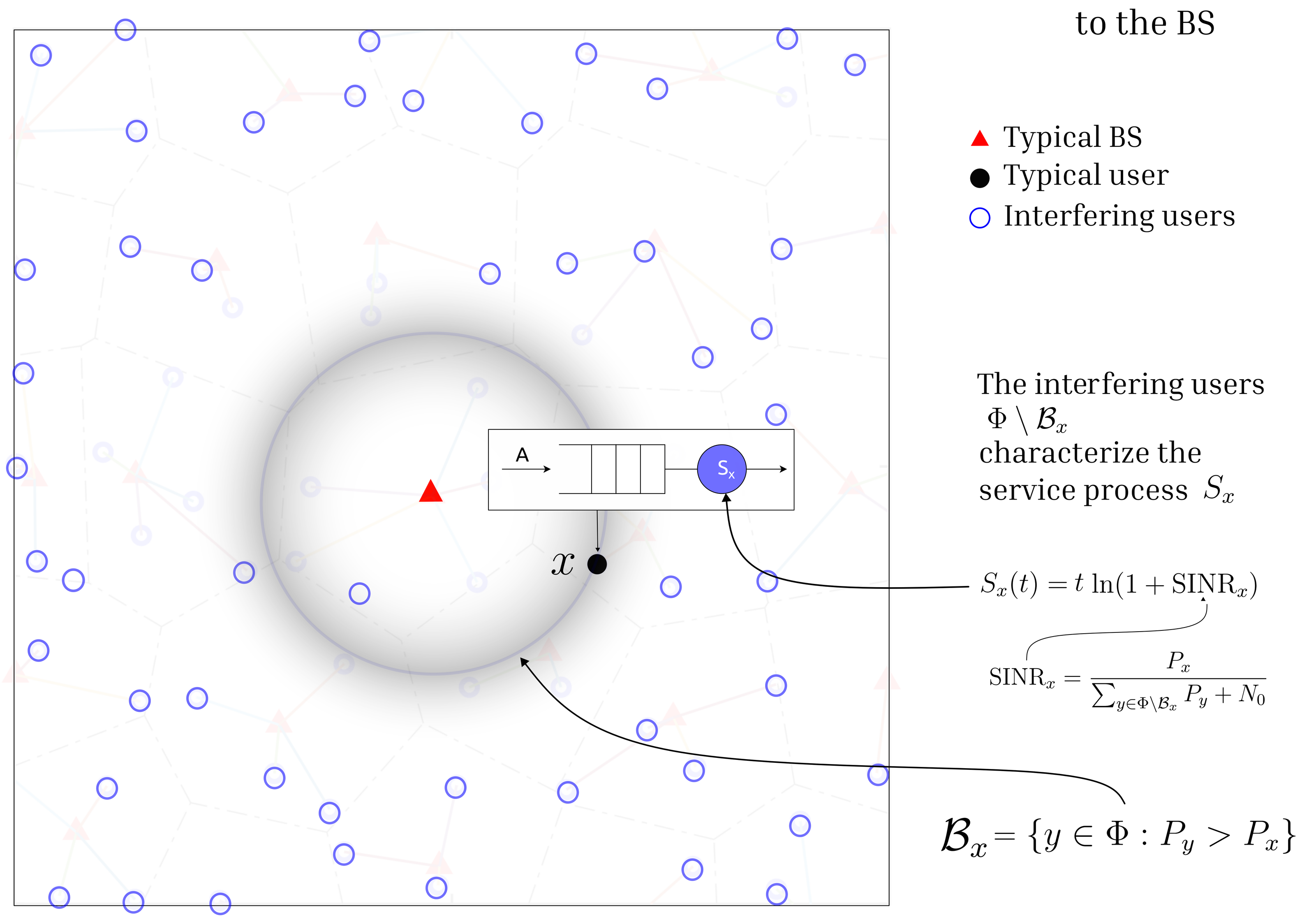

Spatial regulation is introduced in [3]. With shell regulation we study point processes with a number of inteferers at most distance $R$ and at least distance $r$ almost surely upper-bounded, i.e.

$$\Phi(R) - \Phi(r) \leq \sigma + \rho(R-r) + \nu(R^2 - r^2)$$

which leads to a bound of the rate for a typical user $x$:

$$\mathbb{E}\left[e^{-\theta R_x} \,|\, x \in \Phi\right] \leq \exp\left(-\theta\zeta_{(\sigma,\rho,\nu)}(\|x\|)\right)$$

decreasing w.r.t. $\|x\|$ — depends only on the distance to the BS




## References

[1] I. Emre Telatar and Robert G. Gallager. Combining queueing theory with information theory for multiaccess. *IEEE Journal on Selected Areas in Communications*, 13(6):963--969, 1995.

[2] Anne Bouillard, Marc Boyer, and Euriell Le Corronc. *Deterministic network calculus: From theory to practical implementation.* John Wiley & Sons, 2018.

[3] Ke Feng and François Baccelli. Spatial network calculus and performance guarantees in wireless networks. *IEEE Transactions on Wireless Communications*, 2023.

## Scientific cooperation

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