David versus Goliath:Small Cells versus Massive MIMO

Mérouane Debbah

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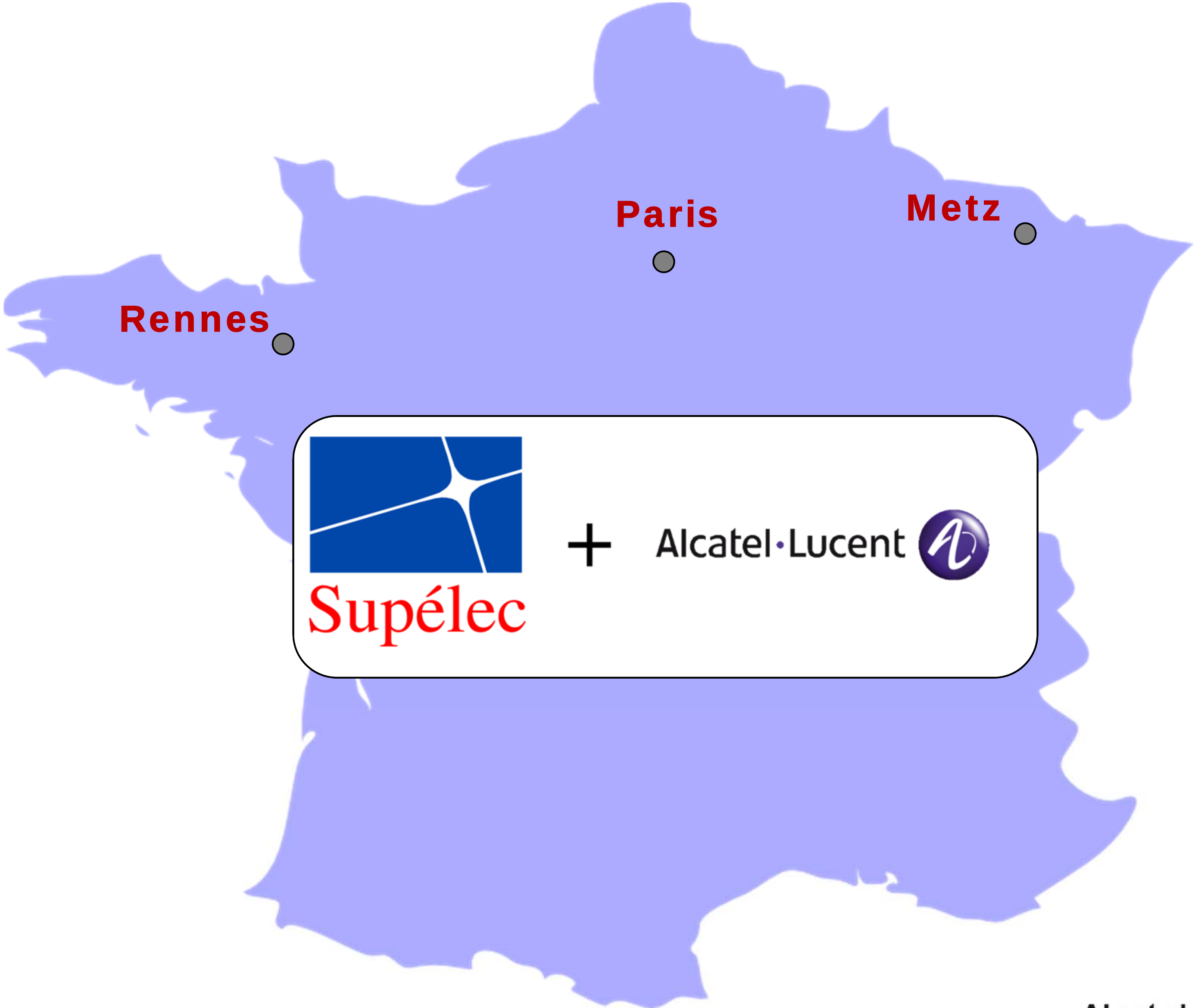

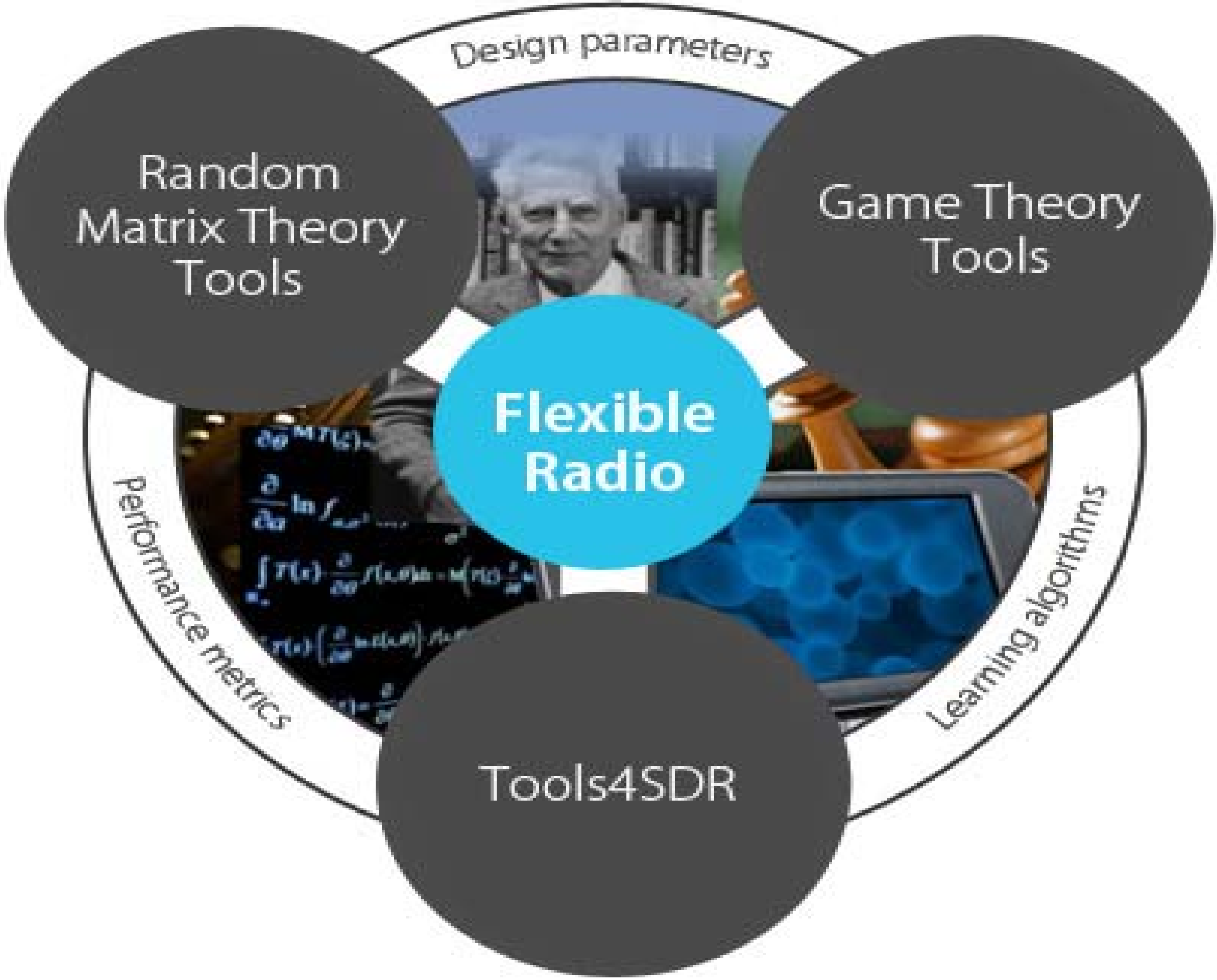

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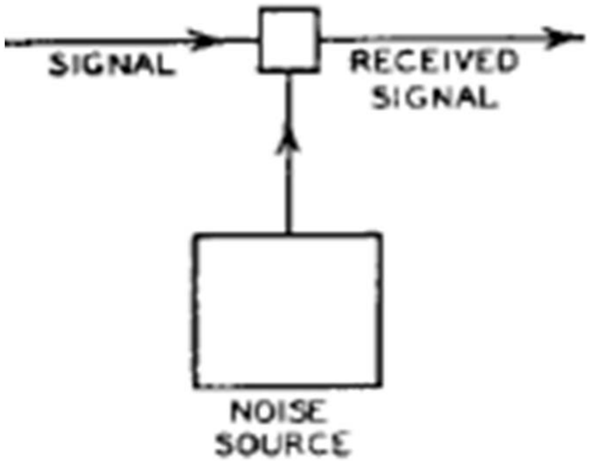
1948: Cybernetics and Theory of Communications

- ”A Mathematical Theory of Communication”, Bell System Technical Journal, 1948, C. E. Shannon
- ”Cybernetics, or Control and Communication in the Animal and the Machine”, Herman et Cie/The Technology Press, 1948, N. Wiener



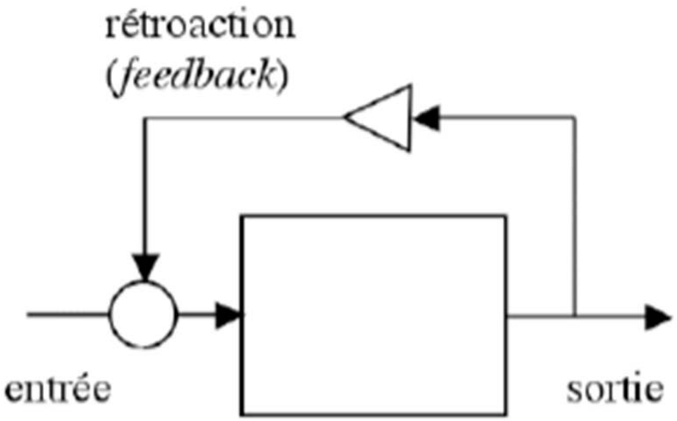
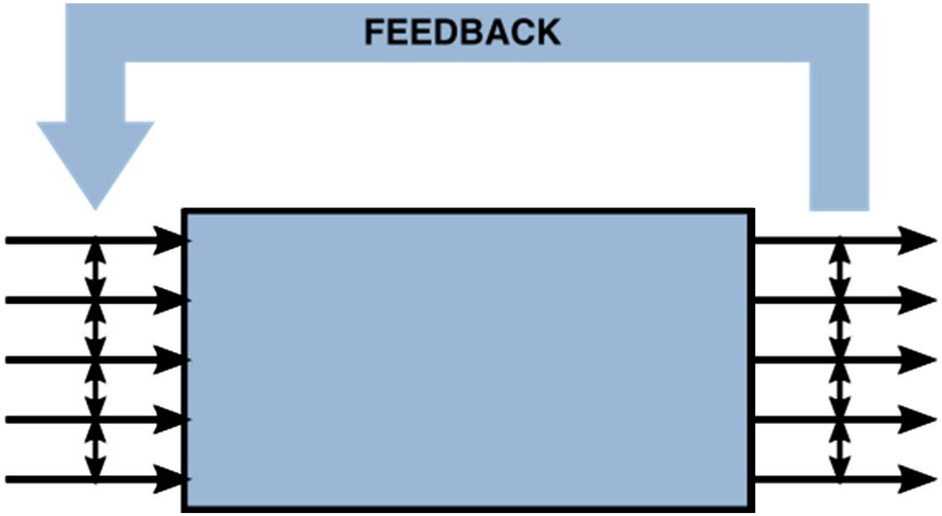


FIG. 1 – Boucle de rétroaction

60 years later...
MIMO Flexible Networks



We must learn and control the black box

- within a fraction of time (dynamics)
- with finite energy (power constraints)

A full theory of MIMO Flexible Networks is still unknown…

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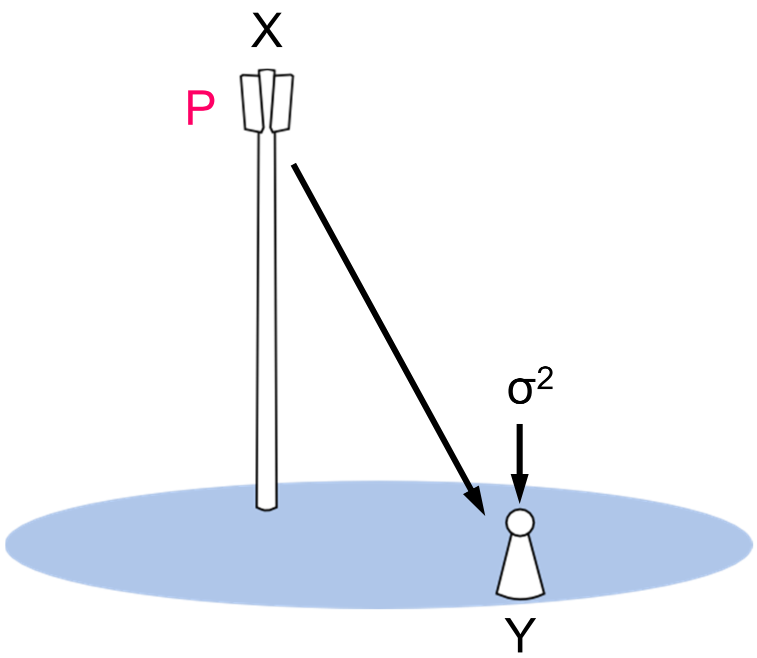
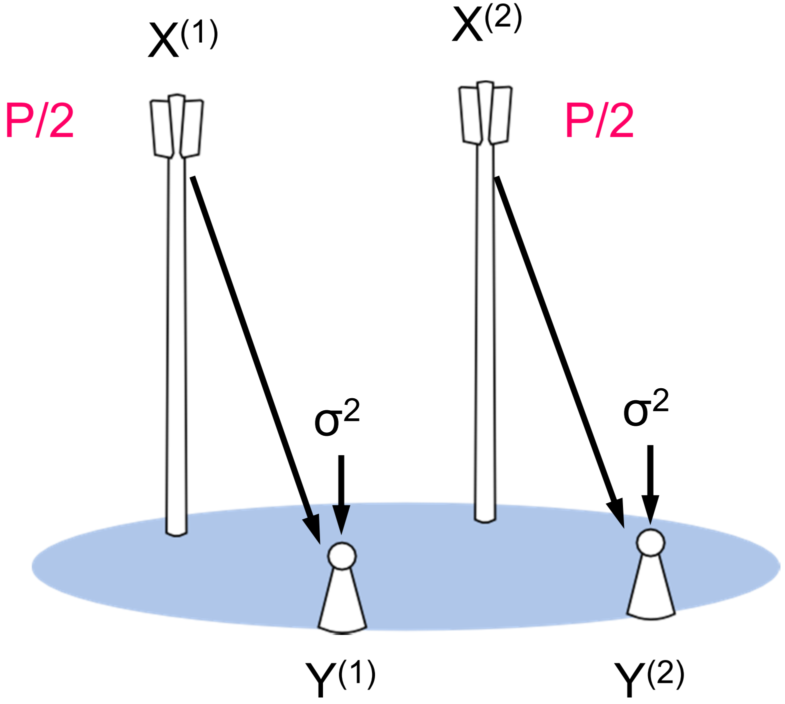
Basics



$$C_1 = \log(1+P/\sigma^2)$$

Basics

$X = X^{(1)} + X^{(2)}$



$C_2^{(1)} = \log(1+P/2\sigma^2)$

$+$

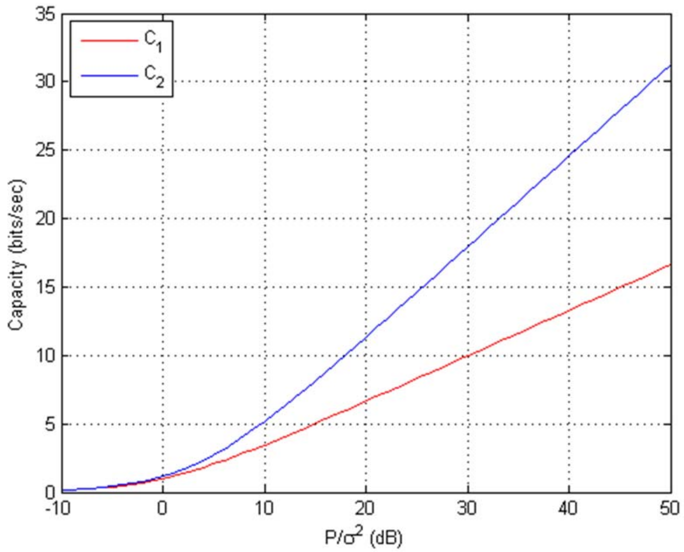
$C_2^{(2)} = \log(1+P/2\sigma^2)$

$\Downarrow$

$C_2 = C_2^{(1)} + C_2^{(2)} = 2\log(1+P/2\sigma^2)$

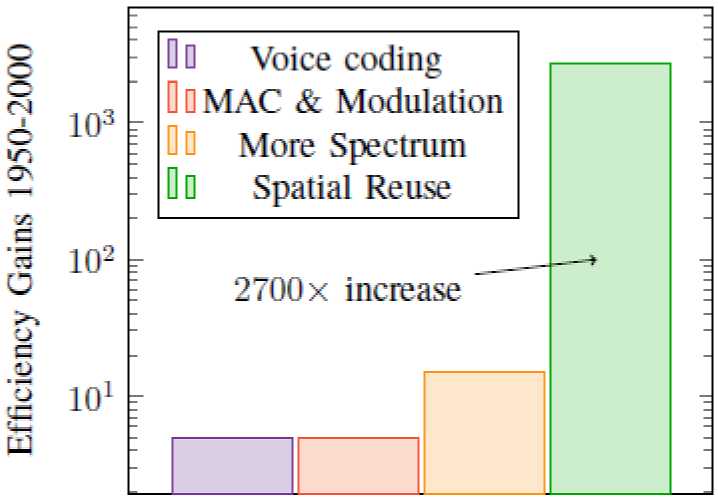
C_1 and C_2, which is better?

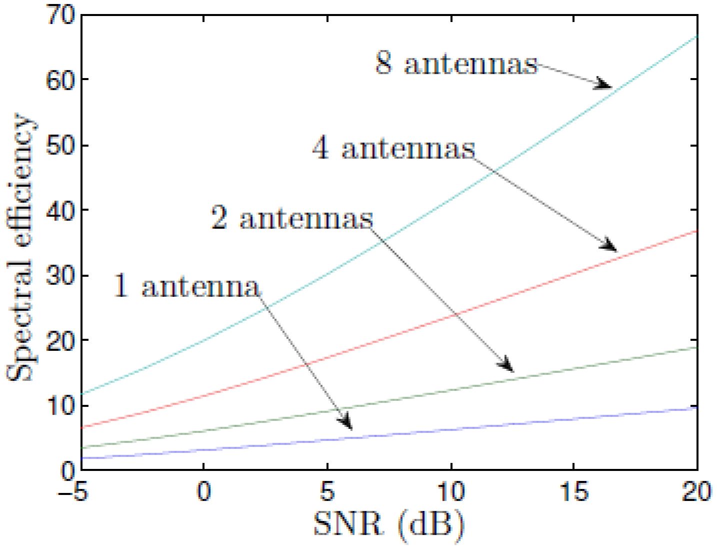
$C_1 = \log(1+P/\sigma^2)$ v.s. $C_2 = 2\log(1+P/2\sigma^2)$



- **Lesson learned:**
  - **High SNR regime**
  - **Orthogonal beams**

Network densification

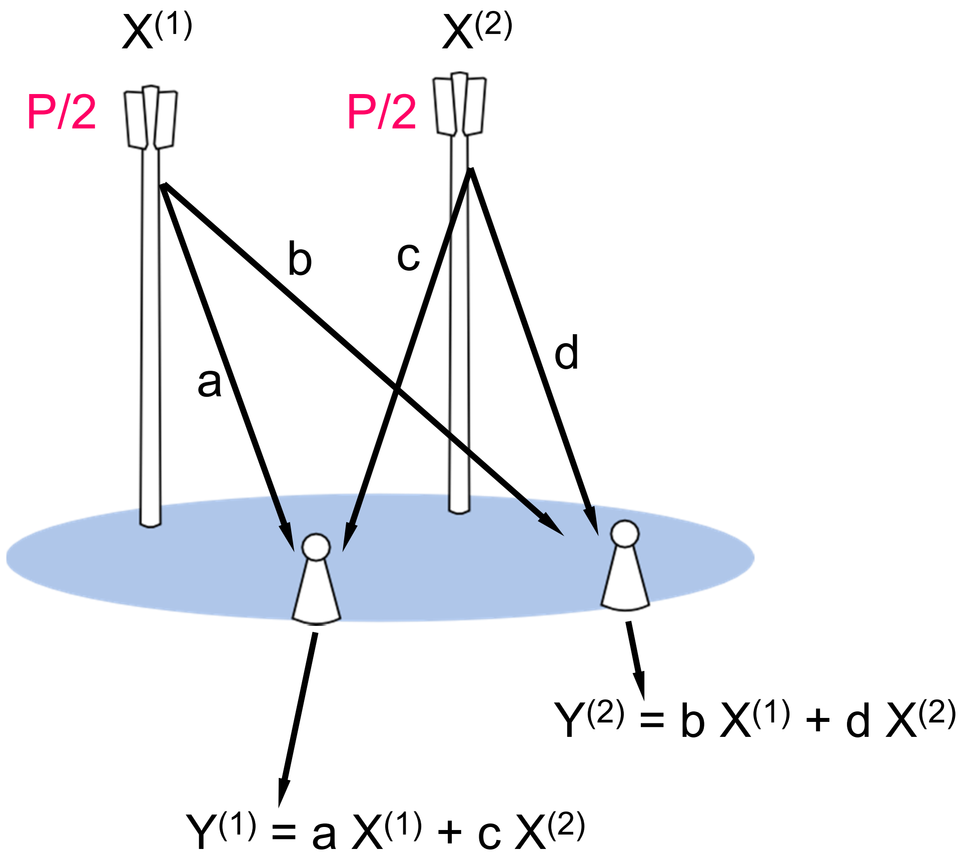




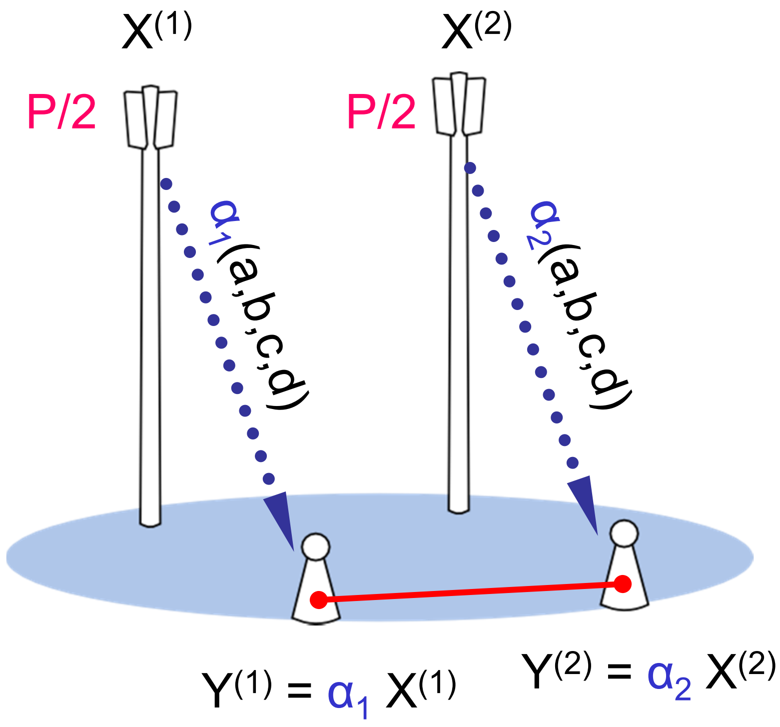
The exploding demand for wireless data traffic requires a massive network densification:

Densification: *"Increasing the number of antennas per unit area"*

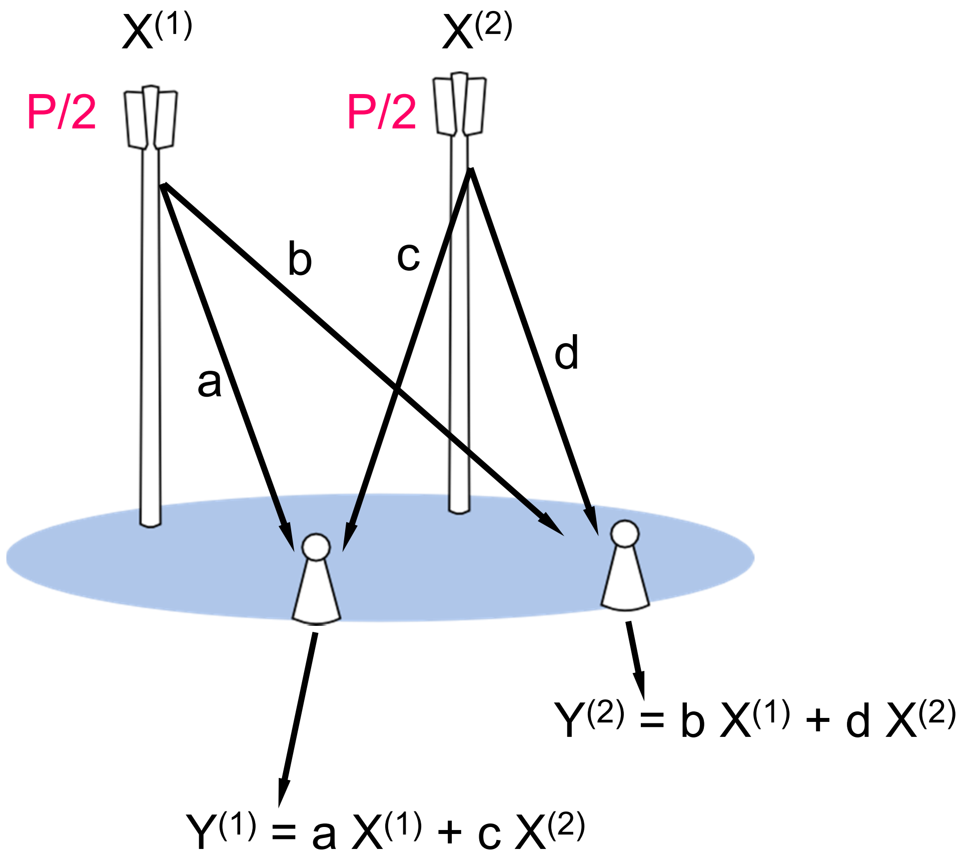
Nature



Receiver cooperation



Transmitter cooperation



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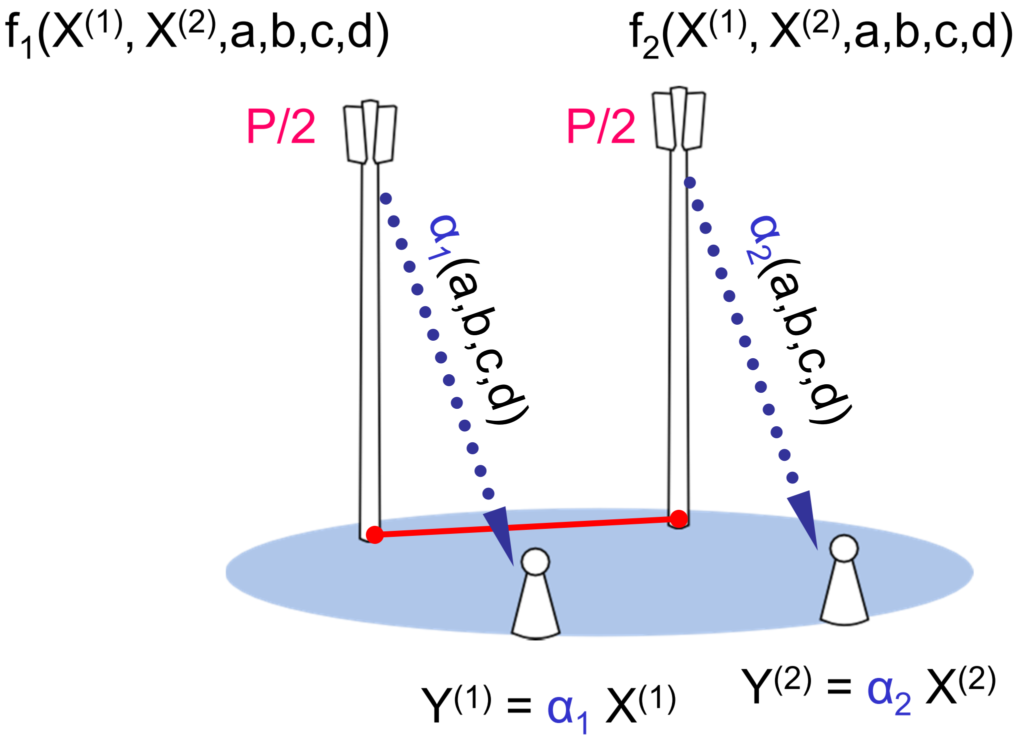
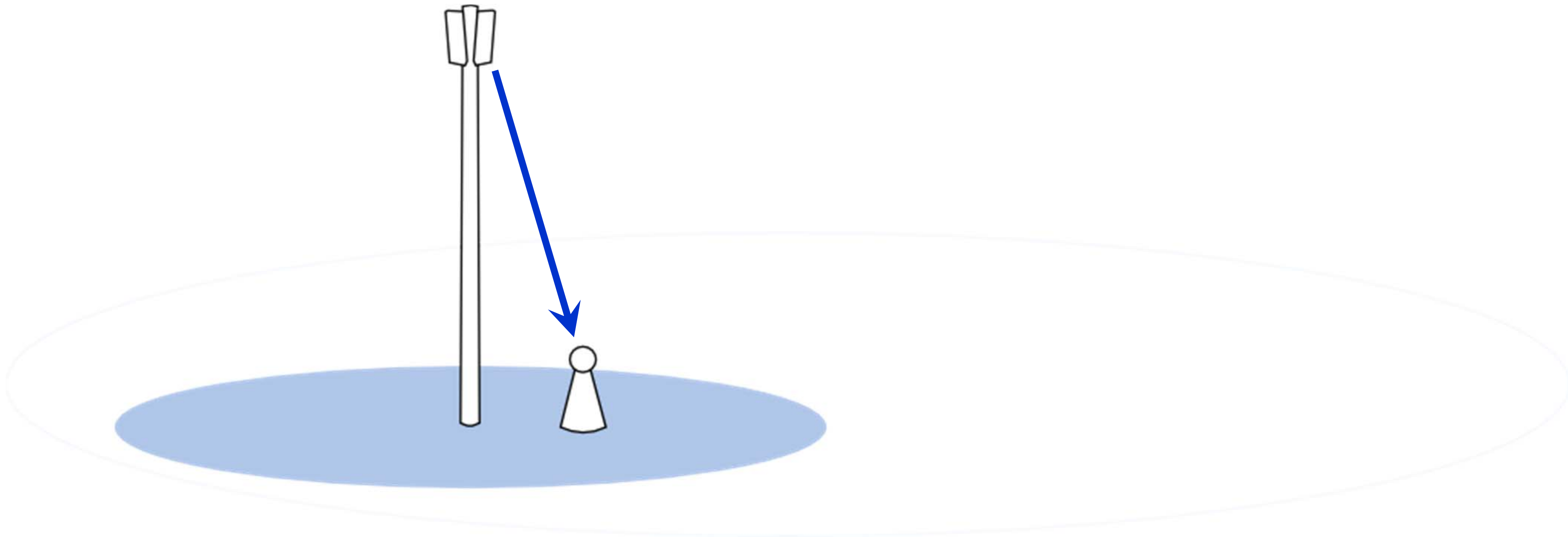
Transmitter cooperation





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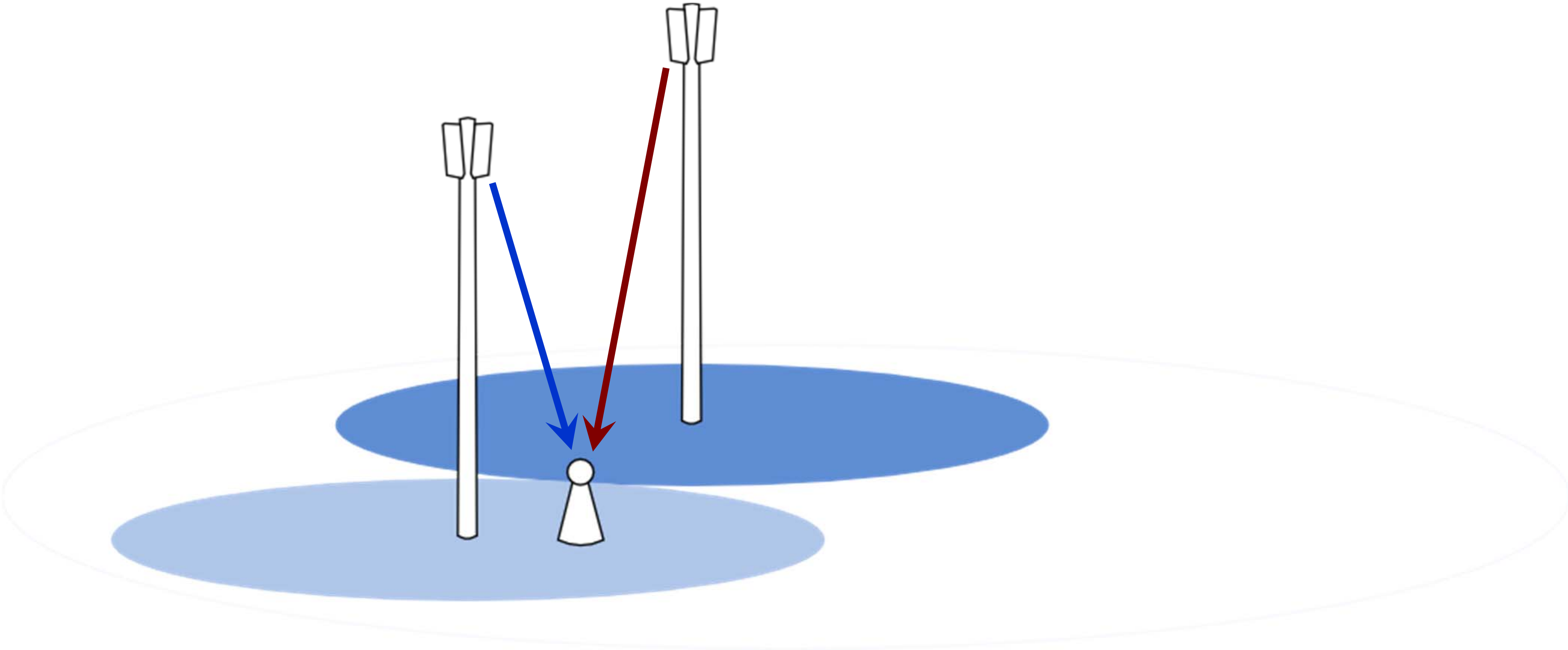

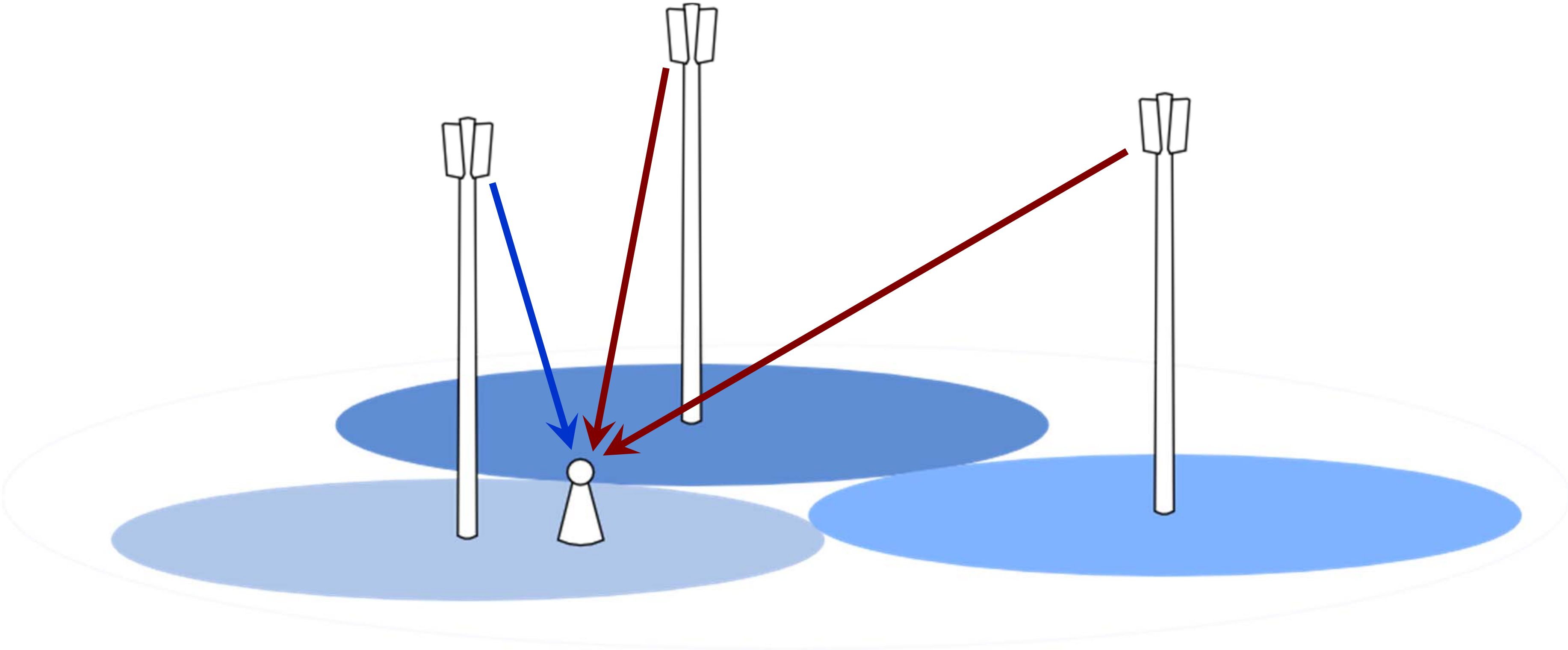

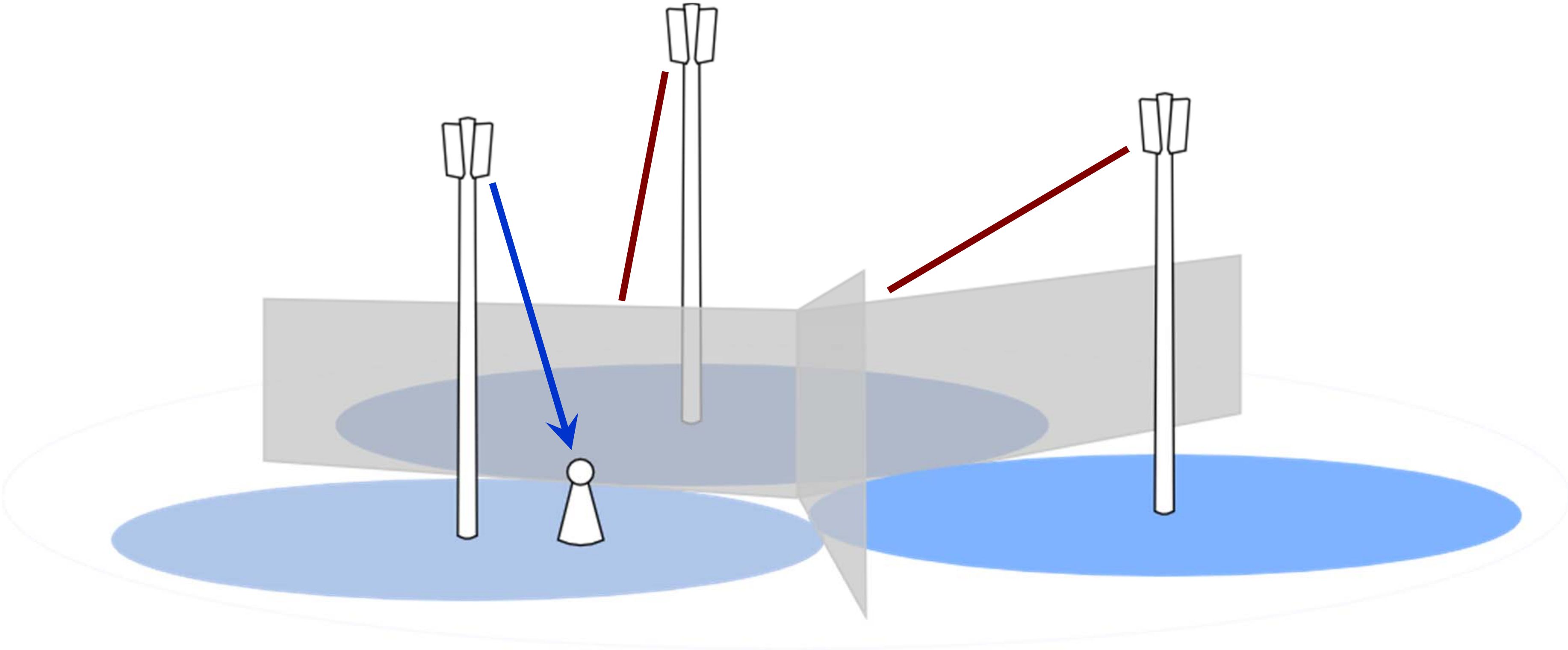

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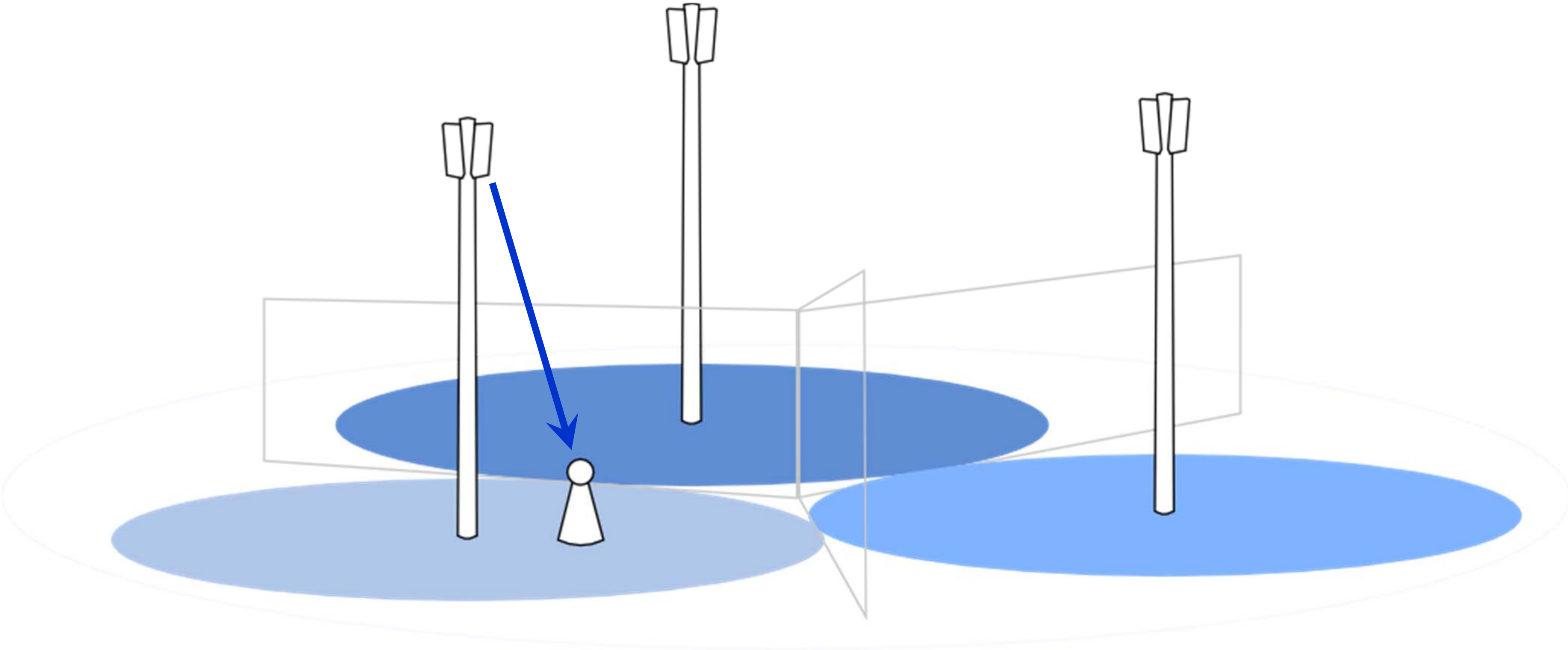

"We build too many walls and not enough bridges."

Isaac Newton

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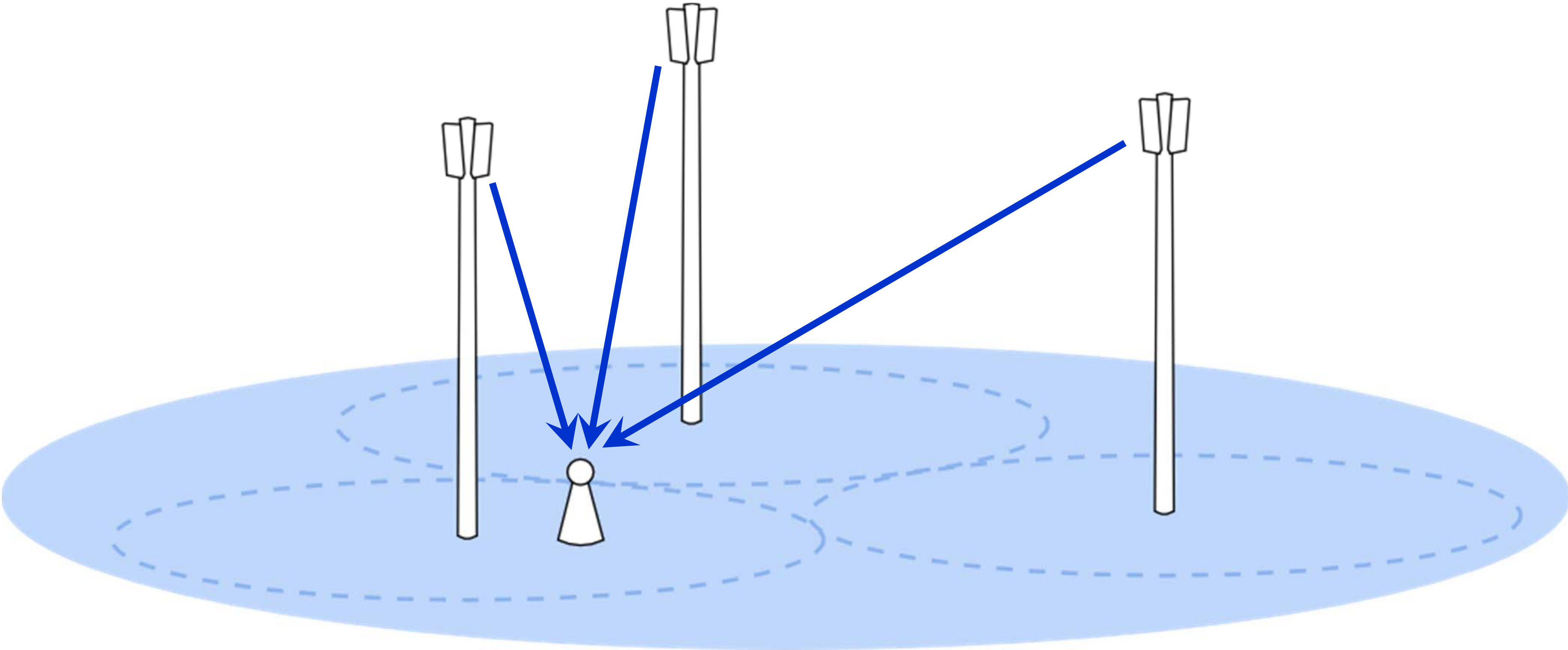

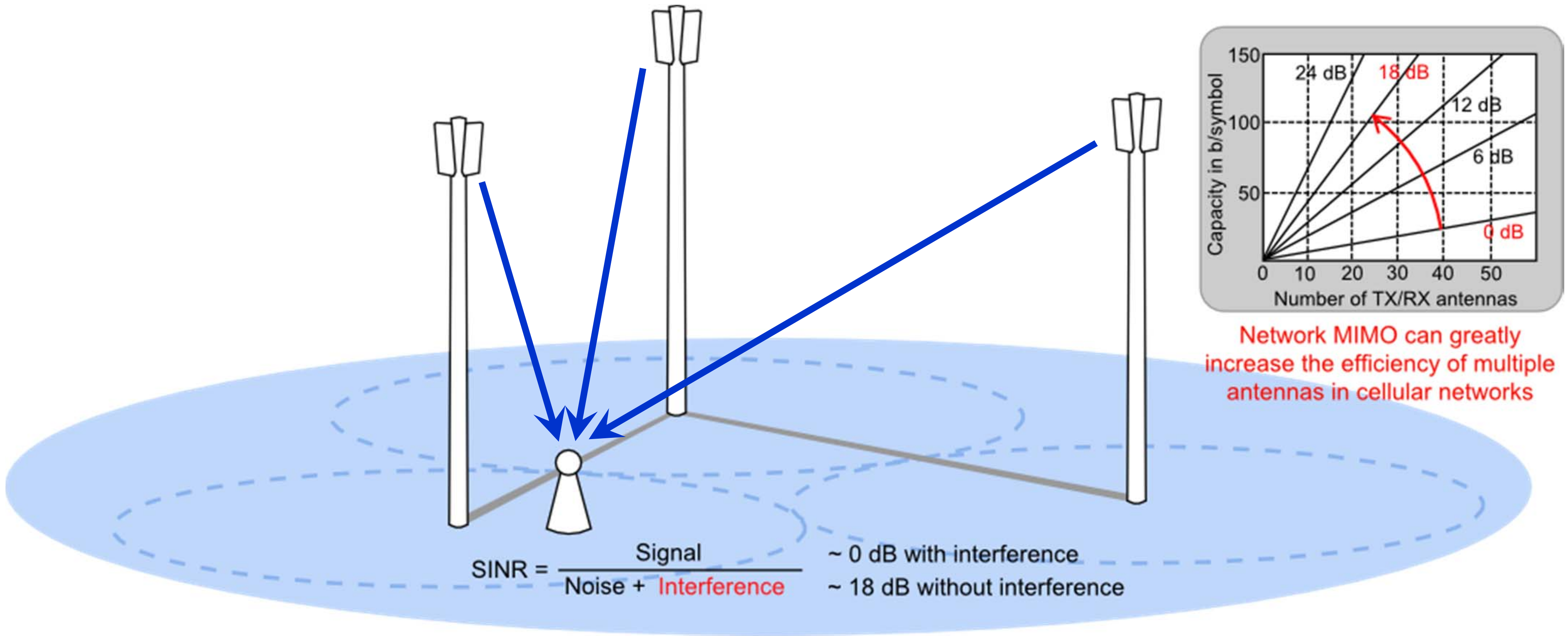

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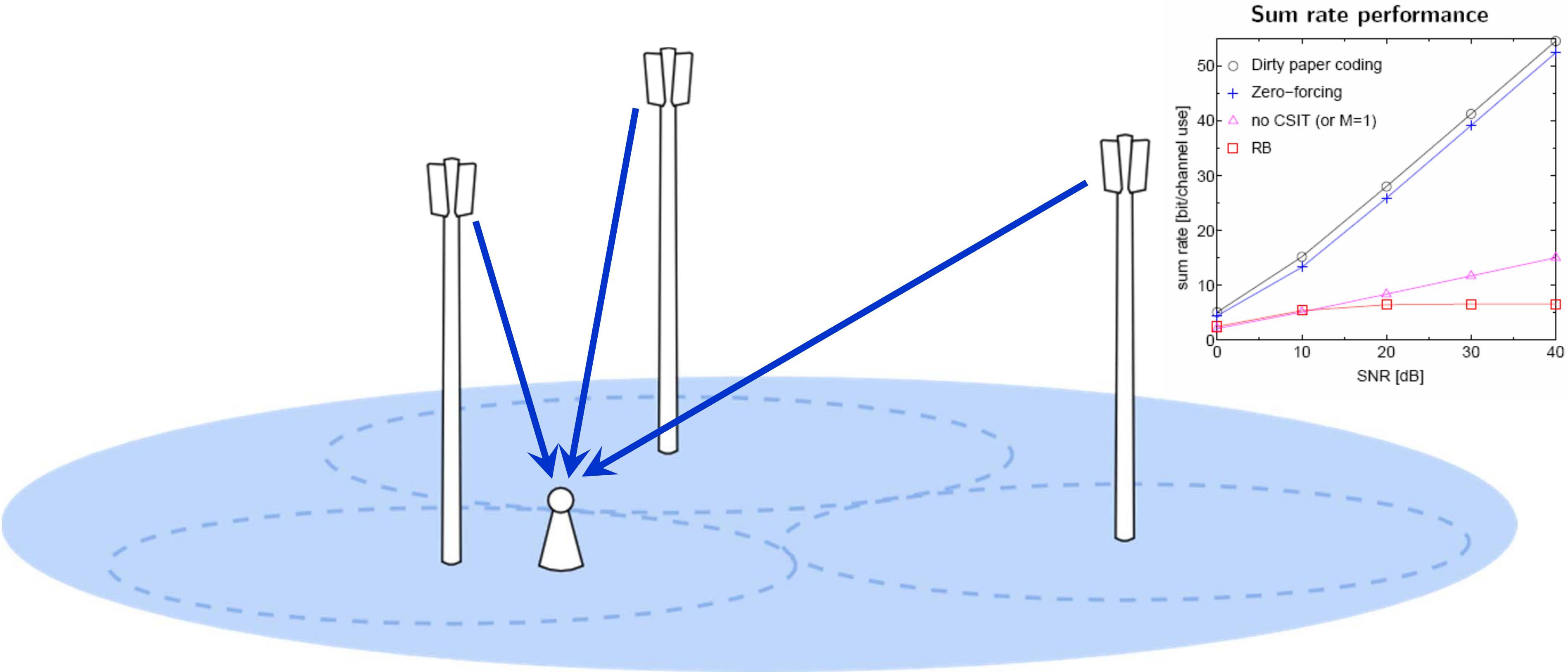
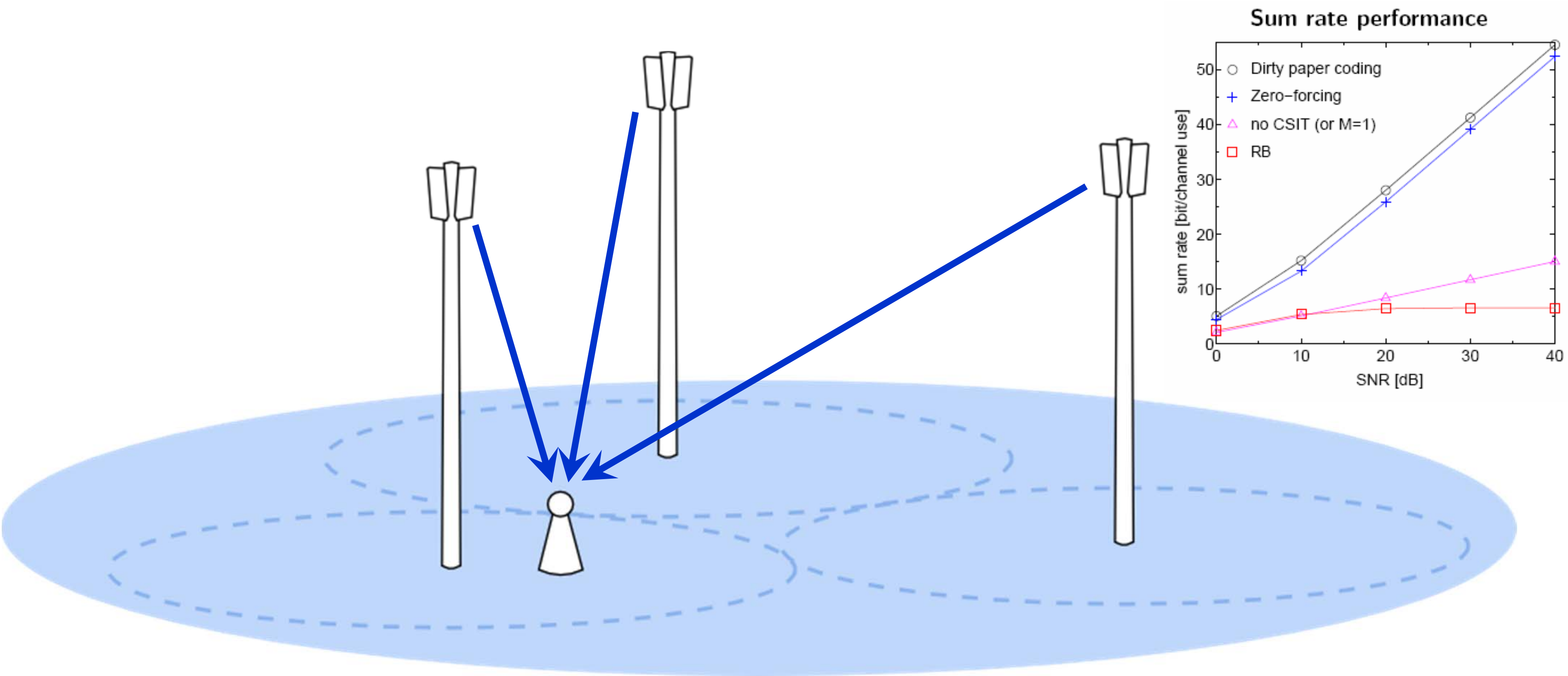
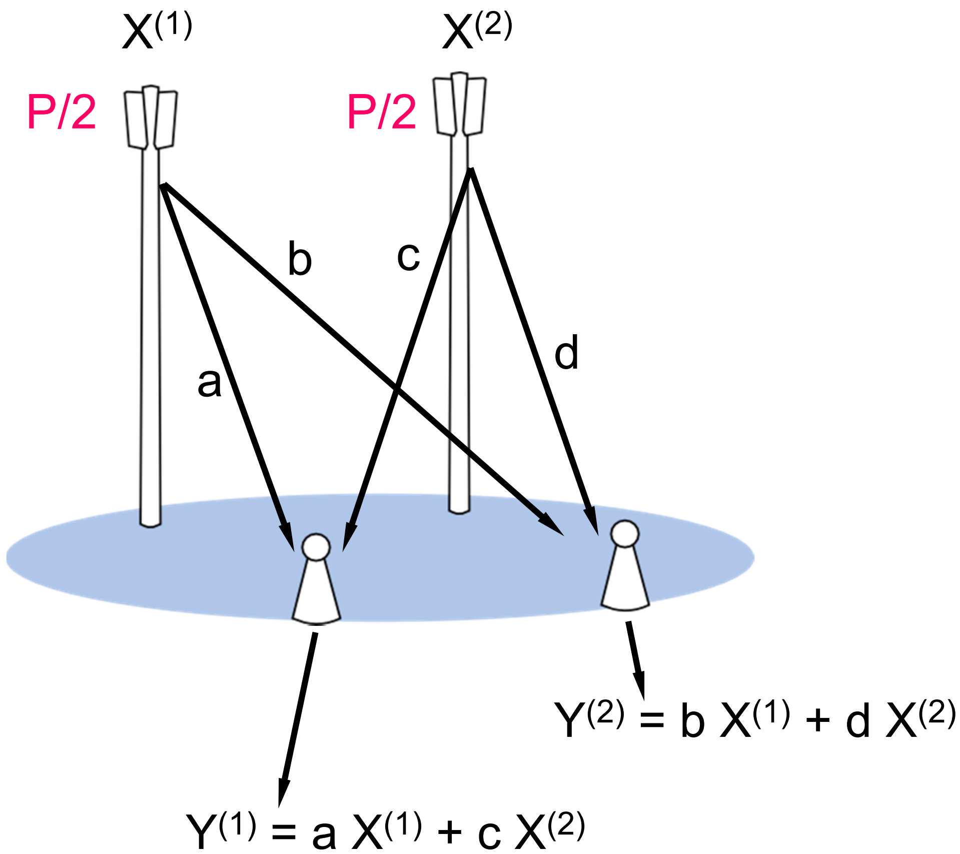


- For large SNR, the sum rate scales as $R_{sum} \sim M \log SNR$ with perfect channel state information at Tx and Rx (CSIT/R)
- The capacity is achieved by a combination of MMSE beamforming and interference pre-cancelation encoding, **Dirty-paper coding**



•Recent results show that a naive ZF with training and analog/digital feedback can indeed achieve the full multiplexing.
•The number of feedback bits should scale as log(SNR).

Our Goal: Self-Learning Base Station



Strategic Games: complete information

Definition: A game with complete information is a game in which each player has full knowledge of all aspects of the game.

In particular, the players know:

- who the other players are.
- what their possible strategies are
- What payoff will result for each player for any combination of moves.

Remark: Complete information is different from perfect information. A game is of perfect information if all players know the moves previously made by all other players (application for sequential games mainly). Complete information requires that every player know the strategies and payoffs of the other players but not necessarily the actions!

Let us start: the prisoner's dilemma

Let us start: the prisoner's dilemma

Context: Two suspects in a major crime are held in a separate cells.

- If they both stay quiet, each will be convicted of the minor offense and spend one year in prison.
- If one and only one of them finks, he will be freed and used as a witness against the other who will spend four years in prison.
- If they both fink, each will spend three years in prison.

Modeling the game

Players: The two suspects

Actions: Each player's set of actions is $\{\text{Quiet}, \text{Fink}\}$

Preferences: We need a function u_1 such as:

$$u_1(\text{Fink}, \text{Quiet}) > u_1(\text{Quiet}, \text{Quiet}) > u_1(\text{Fink}, \text{Fink}) > u_1(\text{Quite}, \text{Fink})$$

For example,

- $u_1(\text{Fink}, \text{Quiet}) = 3.$
- $u_1(\text{Quiet}, \text{Quiet}) = 2.$
- $u_1(\text{Fink}, \text{Fink}) = 1.$
- $u_1(\text{Quite}, \text{Fink}) = 0.$

Games and matrices

		Suspect 2	Suspect 2
		Quiet	Fink
Suspect 1	Quiet	2,2	0,3
Suspect 1	Fink	3,0	1,1

- There are gains from cooperation (each player prefers that both players choose Quite than they both choose Fink).
- However, each player has an incentive to "free ride" (choose fink?) whatever the other player does.
- In any case, for those who don't understand game theory, YOU will always go to jail!

Question: How to solve it? In other words, how to predict the strategy of each player, considering the information the game offers and assuming that the players are rational?

Methods to solve static games

- Iterated dominance.
- Nash Equilibrium.
- Mixed Strategies.

In all these techniques, we assume non-cooperative games. Cooperative games require agreements between the decision makers and might be more difficult to realize (additional signalization).

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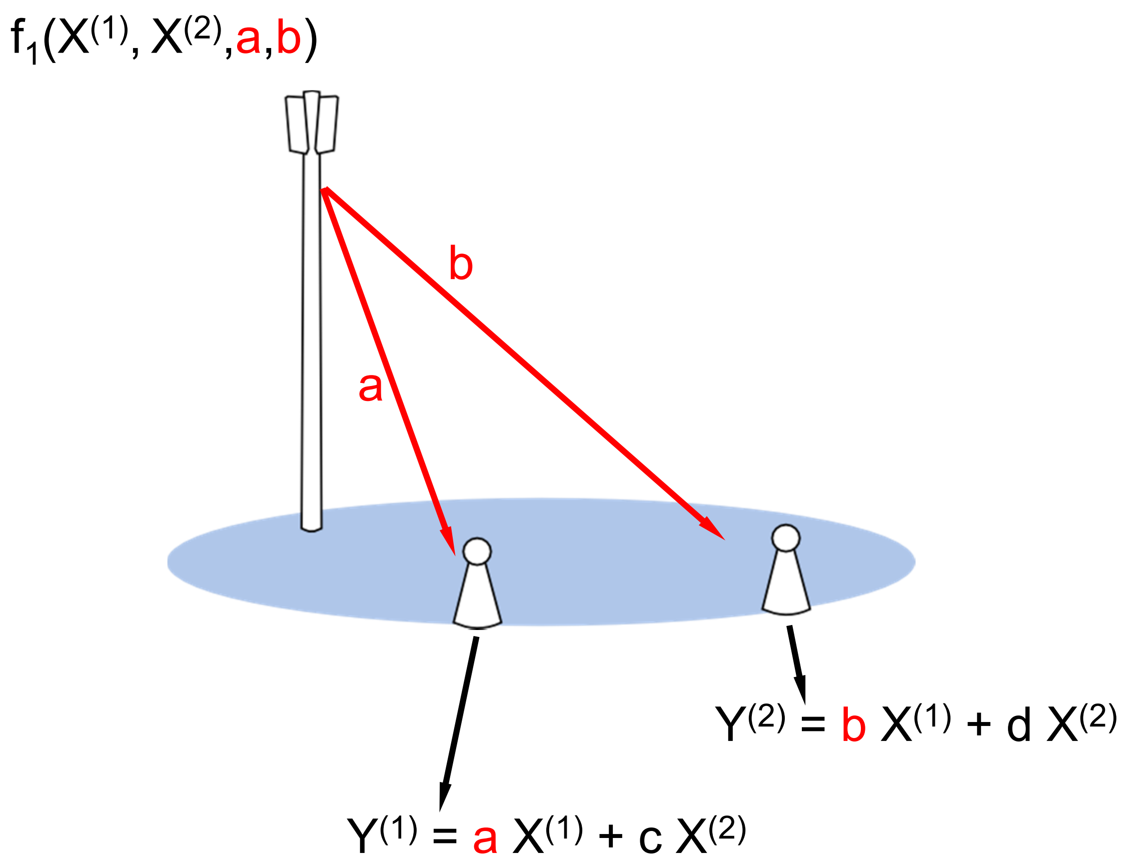

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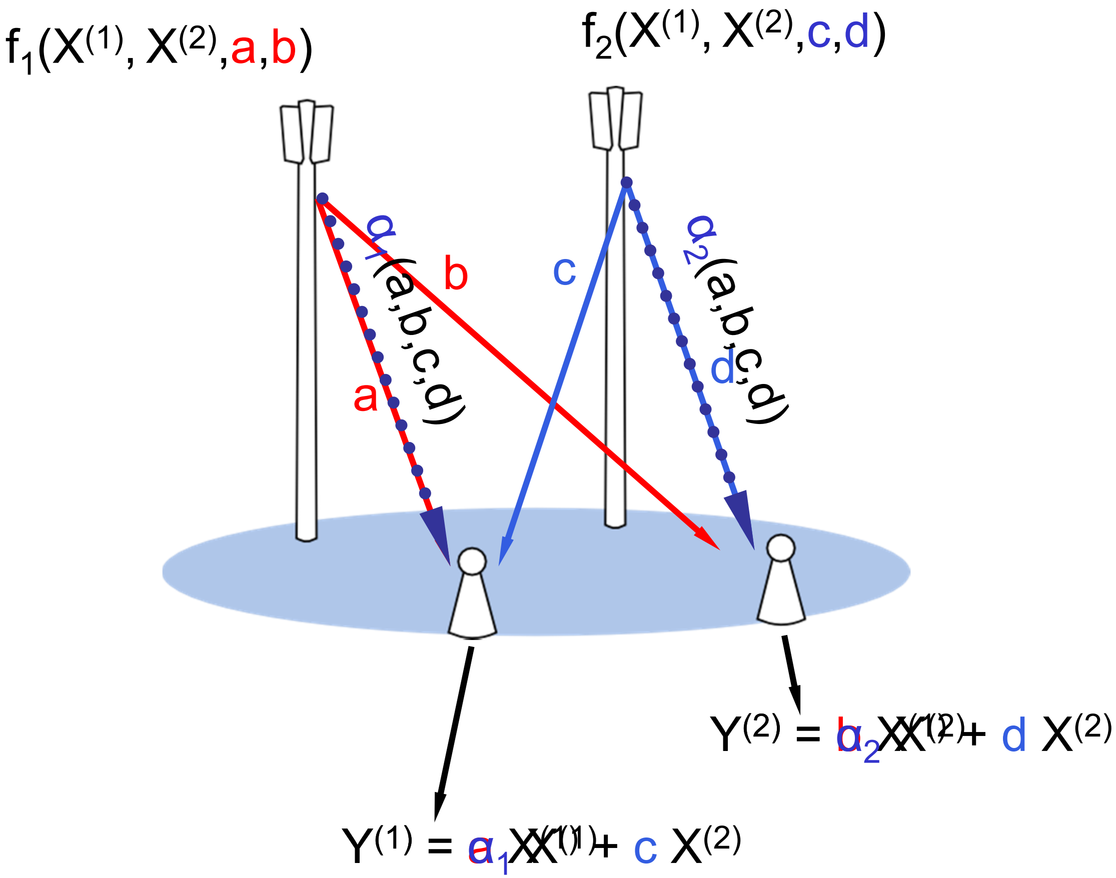

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Shannon's Small Self-Learning Mouse

Computers and Automata*

CLAUDE E. SHANNON†, FELLOW, IRE

C. E. Shannon first became known for a paper in which he applied Boolean Algebra to relay switching circuits; this laid the foundation for the present extensive application of Boolean Algebra to computer design. Dr. Shannon, who is engaged in mathematical research at Bell Telephone Laboratories, is an authority on information theory. More recently he received wide notice for his ingenious maze-solving mechanical mouse, and he is well-known as one of the leading explorers into the exciting, but uncharted world of new ideas in the computer field.

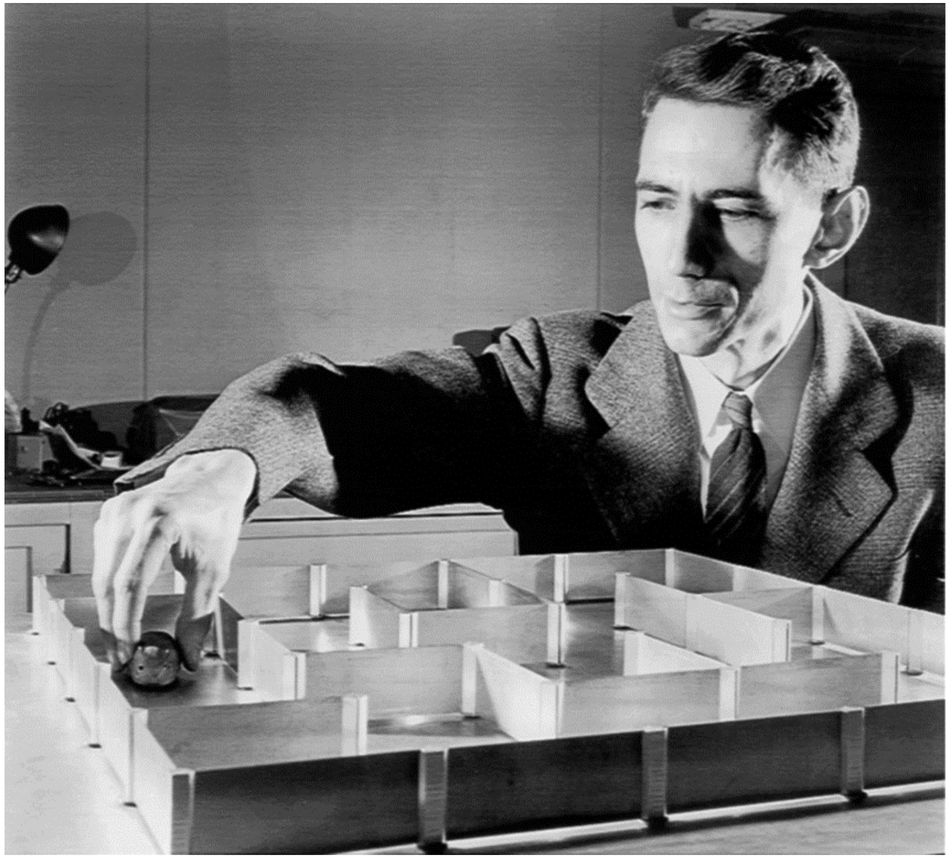
The Editors asked Dr. Shannon to write a paper describing current experiments, and speculations concerning future developments in computer logic. Here is a real challenge for those in search of a field where creative ability, imagination, and curiosity will undoubtedly lead to major advances in human knowledge.—*The Editor*

***Summary*—This paper reviews briefly some of the recent developments in the field of automata and nonnumerical computation. A number of typical machines are described, including logic machines, game-playing machines and learning machines. Some theoretical questions and developments are discussed, such as a comparison of computers and the brain, Turing's formulation of computing machines and von Neumann's models of self-reproducing machines.**

* Decimal classification: 621.385.2. Original manuscript received by the Institute, July 17, 1953.
† Bell Telephone Laboratories, Murray Hill, N. J.

Introduction

SAMUEL BUTLER, in 1871, completed the manuscript of a most engaging social satire, *Erewhon.* Three chapters of *Erewhon*, originally appearing under the title "Darwin Among the Machines," are a witty parody of *The Origin of Species*. In the topsy-turvy logic of satirical writing, Butler sees machines as gradually evolving into higher forms. He considers the classification of machines into genera, species and vari-



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