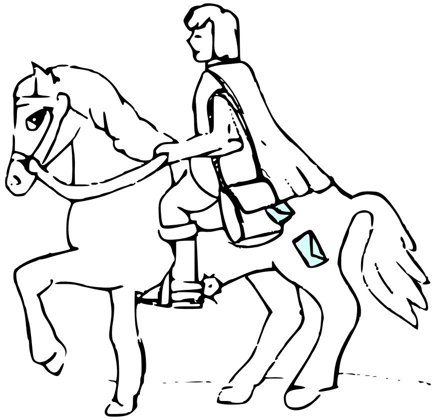

BIG
BIGGER
BIGGEST

What should we expect from 6G antennas ?

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URSI GASS 2020, Rome (WEB presentation)

Research directions for 6G

?

- Extremely large aperture array
  - Cell-free Massive MIMO
  - Very large aperture Massive MIMO
  - Distributed MIMO
  - Radio stripes
- Holographic Massive MIMO
  - Large intelligent surfaces
  - Holographic beamforming
  - Intelligent walls
  - Reconfigurable reflectarrays
  - Software-controlled metasurfaces
  - Intelligent reflecting surfaces

Ref: Massive MIMO is a Reality—What is Next? Five Promising Research Directions for Antenna Arrays, Digital Signal Processing, Elsevier, Nov. 2019

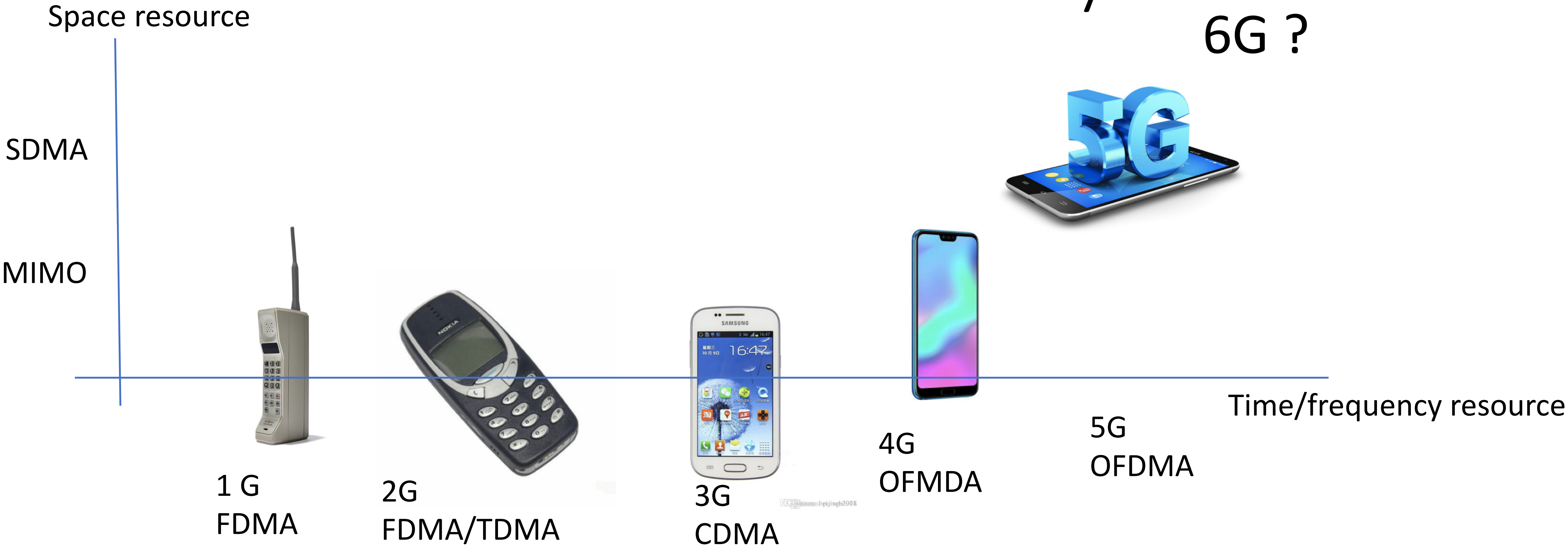
Research directions for 6G (comment)

There is an active research on antenna systems for 6G. Many different solutions have been proposed.

In this presentation the trend of antenna cellular systems will be analised in terms of some ‘high level’ parameters

In order to introduce such parameters we need to analyze how the space/time/frequency resources that the communication system makes available are used in the different generations of cellular communication system

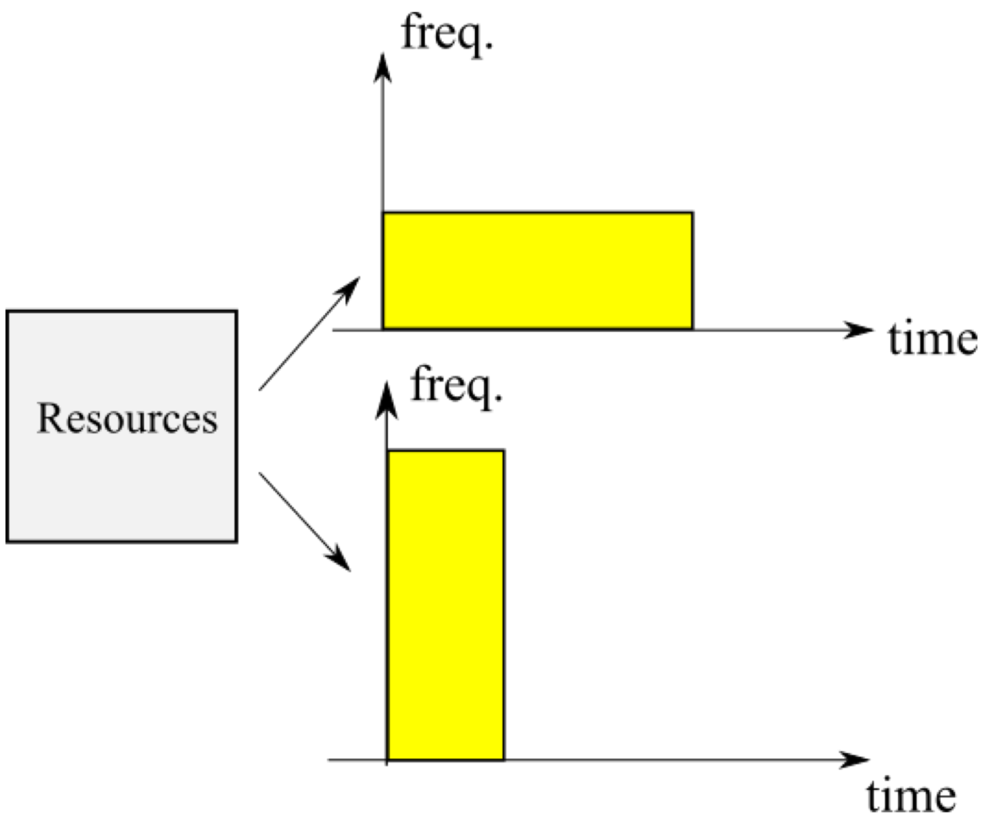
From 1G to 5G and beyond…



2G-4G generations are characterized by an increasing aggressive use of the time/frequency resource, represented by more effective modulations, freq./time division access strategies and increase of bandwidth

5G for the first time offers a significant improvement in the use of the space resource available on the communication channel

The use of the time/frequency resource in 5G



The unit information element is the Resource Element (1 OFDM symbol x 1 subcarrier)

Flexible numerology: 1 RE is mapped in the time/frequency domain in a flexible way, roughly keeping the time x frequency ‘area’ constant

Shannon number of Degrees of Freedom (“time/freq. domain”) ***TNDF=2BT***

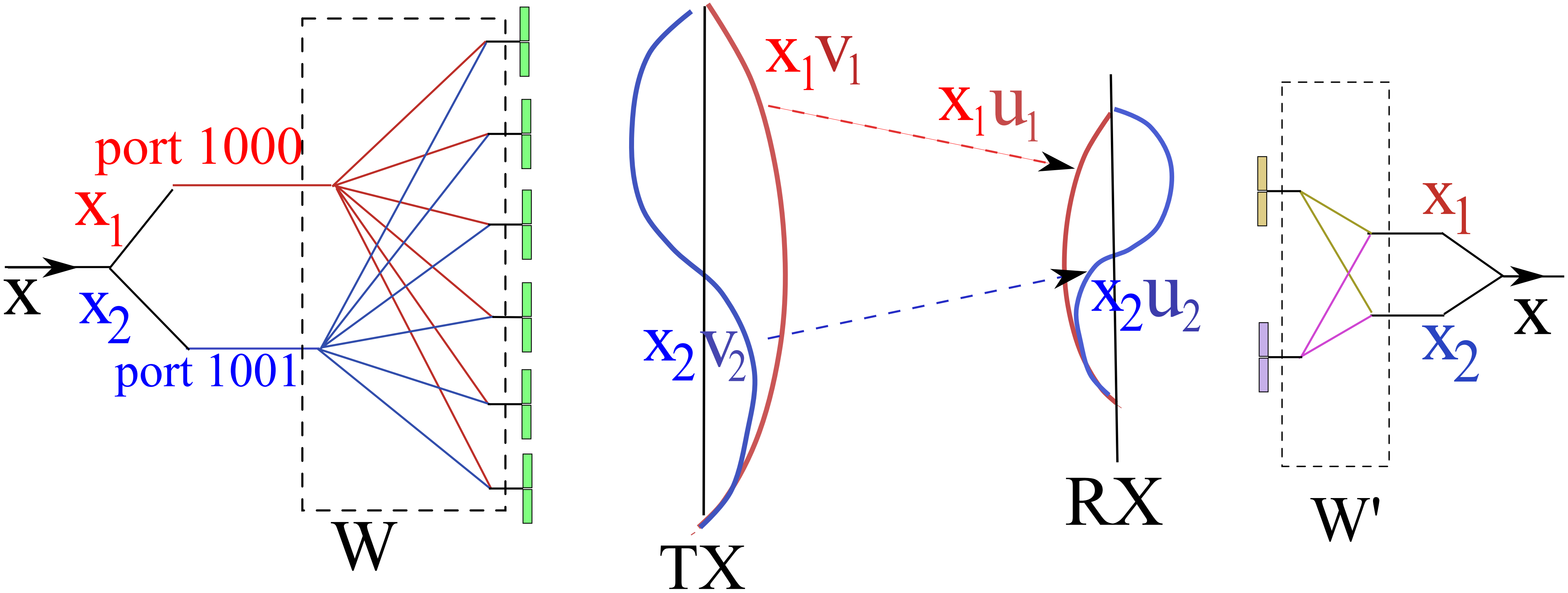
T: time, B: bandwidth

The TNDF gives the ‘maximum’ amount of resources available in the time/frequency domain

The use of the space resource in 5G

- The use of the space resource at the physical layer is based on the concept of the **antenna port**
- an antenna port is defined such that **the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed**
- MIMO and MU-MIMO transmit user data on different layers associated to different PDSCH antenna ports (number port starting form 1000)
- How antenna ports are mapped in space field configurations?
- We need to go ‘below’ the physical layer, at the the ‘deep physical layer‘ level

Antenna ports at the the ‘deep physical layer’



Ref: "A Theoretical and Experimental Investigation on the Measurement of the Electromagnetic Field Level Radiated by 5G Base Stations," *IEEE Access*, 2020

Antenna ports (Comment)

The figure shows an idealized scheme of a spatial multiplexing MIMO communication system. From the left: the symbol **x** is divided into two subsymbols x_1 and x_2 and sent to the transmitting (TX) antennas through a proper beamforming network (matrix **W**); the current density distribution on the TX antennas is represented by the superposition of two current distributions v_1 and v_2, that give an incident field on the receiving (RX) antennas equal to u_1 and u_2 respectively; the amplitude and phase of the currents are modulated by x_1 and x_2. giving a global current density distribution on the TX antennas equal to $(x_1v_1 + x_2v_2)$; consequently, the field on the RX antennas is $(x_1u_1 + x_2u_2)$; a (spatial) sampling of the field using multiple RX antennas allows to retrieve x_1 and x_2 by a proper data processing (matrix $\mathbf{W}_0$), and hence **x**.

Ref: "A Theoretical and Experimental Investigation on the Measurement of the Electromagnetic Field Level Radiated by 5G Base Stations," *IEEE Access*, 2020

Resources in the space domain

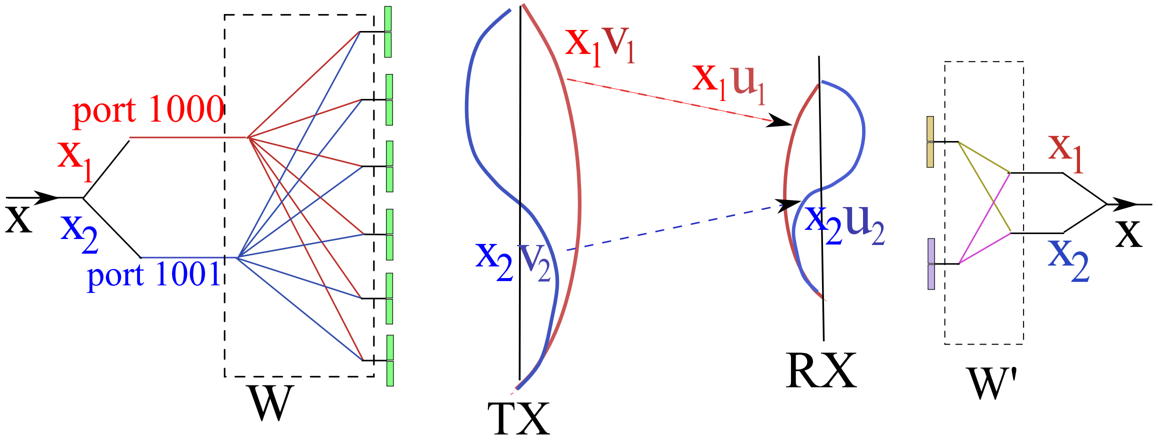
- The field configuration observed on a surface domain is treated as a (two dimensional) signal, having a (spatial) bandwidth in a (space) domain that is the support of the (two dimensional) function
- The function is characterized by a (spatial) bandwidth and the (normalized) extension of the observation domain
- Space: space bandwidth W (normalized) space Ω

Number of Degrees of Freedom (in the "spatial frequency-space domain"): SNDF=2W Ω

Same role of the TNDF but for information transmitted using the space resource

Ref:"On the role of the number of degrees of freedom of the field in MIMO channels." *IEEE Transactions on Antennas and Propagation* , 2006

Antenna ports at the the ‘deep physical layer’

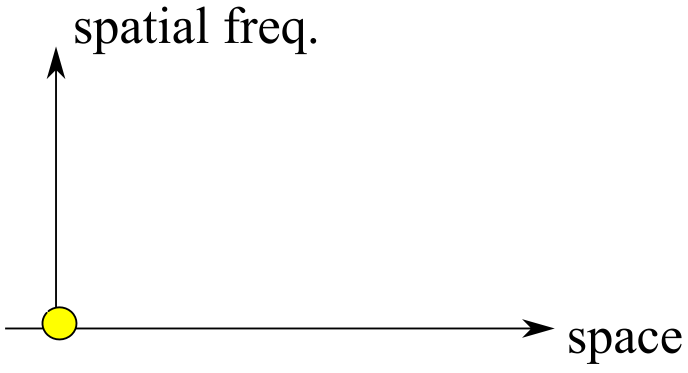


In case of planar radiating surfaces the SNDF is almost equal to 4 times to the electrical area of the radiating surface, i.e. $4\ A/\lambda^2$, wherein A is the area and λ is the wavelength

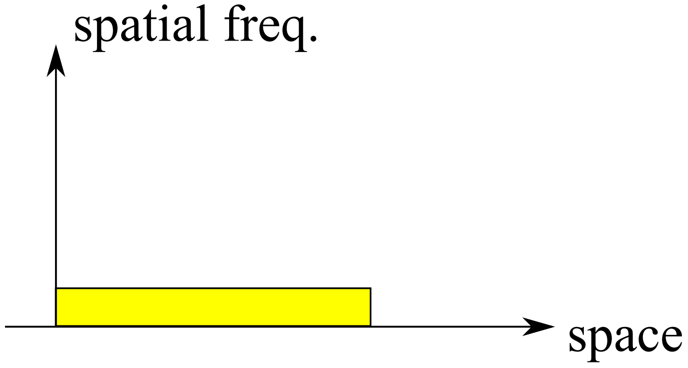
The SNDF is the least upper bound for the number of spatial parallel channels (layers) of any communication system based on space coding

Ref: "On the role of the number of degrees of freedom of the field in MIMO channels." *IEEE Transactions on Antennas and Propagation* , 2006

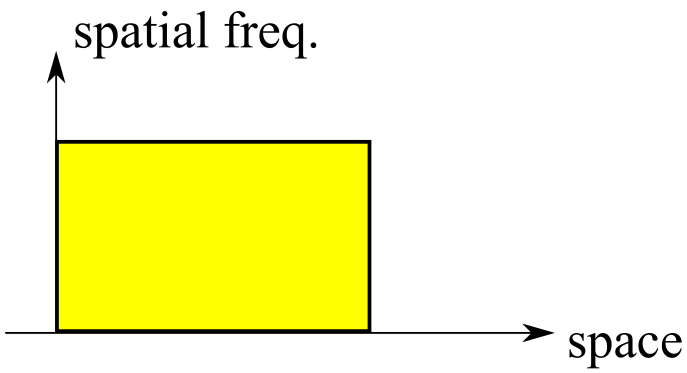
The use of the space resources



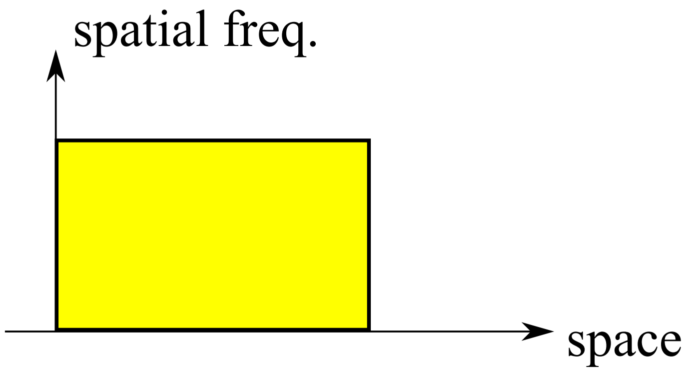
Fixed beam antennas



MU-MIMO

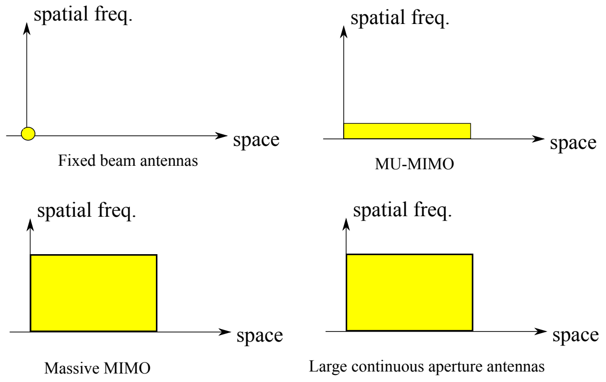


Massive MIMO



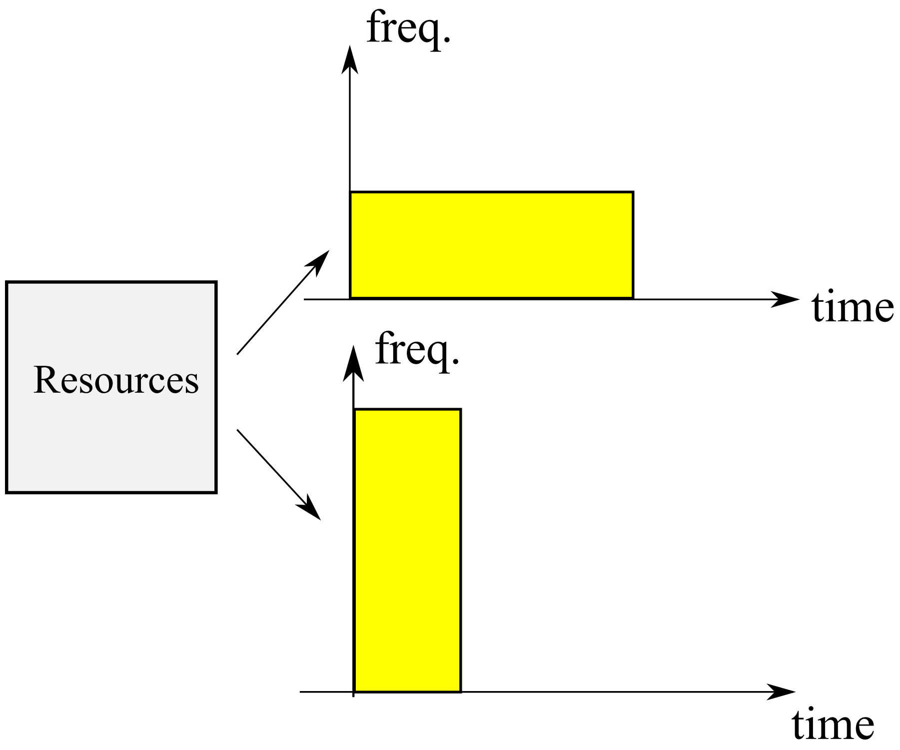
Large continuous aperture antennas

The use of the space resources (comment)

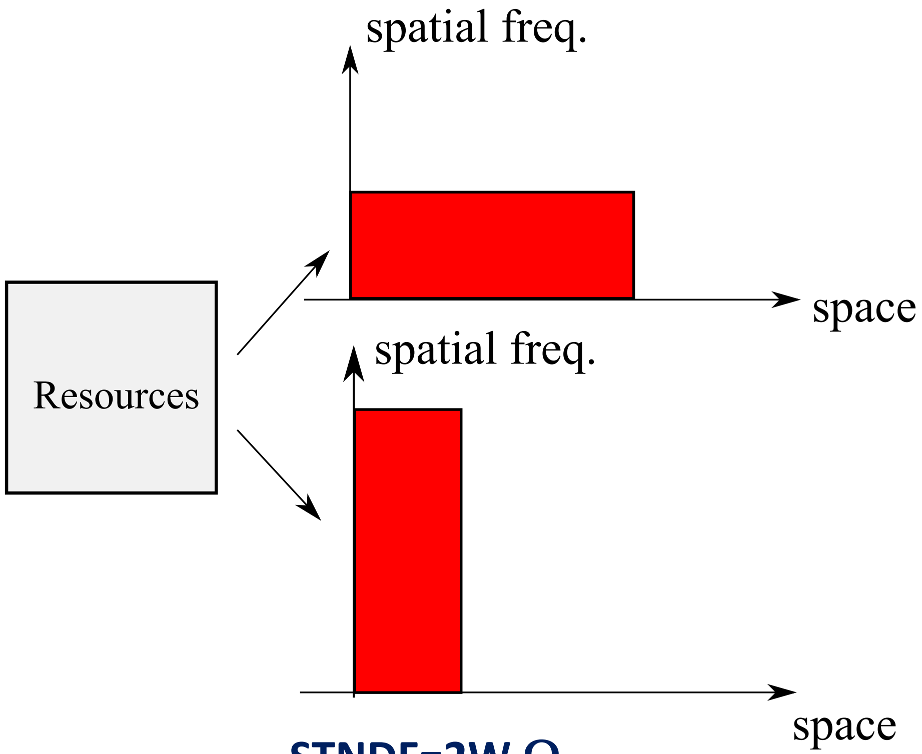


Different “kind of antennas” use different space/spatial bandwidth
For example, Massive MIMO use a larger spatial bandwidth compared to standard MU-MIMO
The maximum amount of information reliably transmissible using space-coding is given by the space-spatial bandwidth product, i.e. the area of the rectangle

Space/time resources



STNDF=2BT



STNDF=2W Ω

Number of Degrees of Freedom (“in space/time”)

STNDF=2BT 2W Ω

Space/time resources (comments)

In space-time coding the maximum amount of information that can be transmitted is given by the product of the Number of Degrees of Freedom in space and in time (“STNDF”)

Consequently, there are 4 main ways to increase information:

1) Increase the observation time T

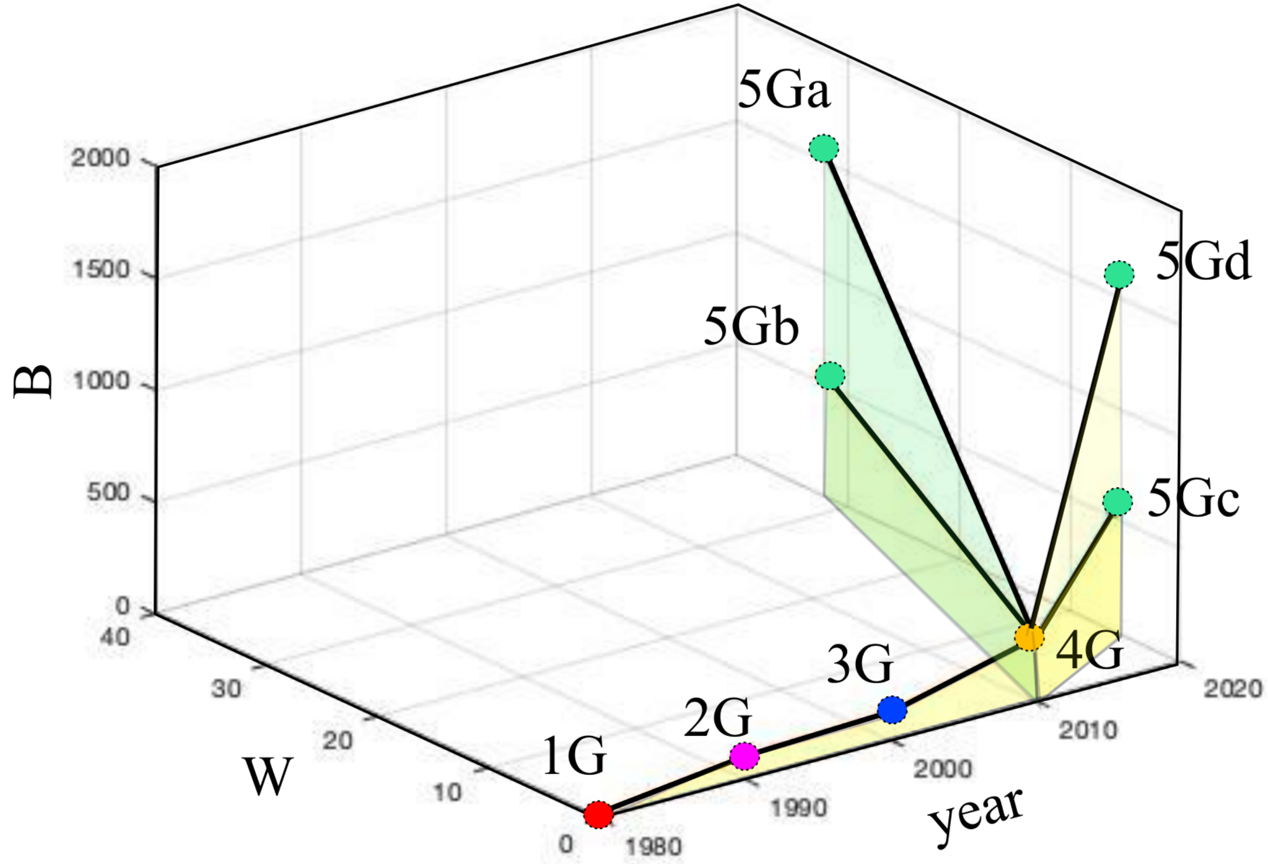
2) Increase the bandwidth B of the (time) signal

3) Increase the observation domain Ω where to place the receiving elements

4) Increase the spatial bandwidth W of the field increasing the dimension of the transmitting area

Let us study the STNDF **per unit time T and unit area Ω**

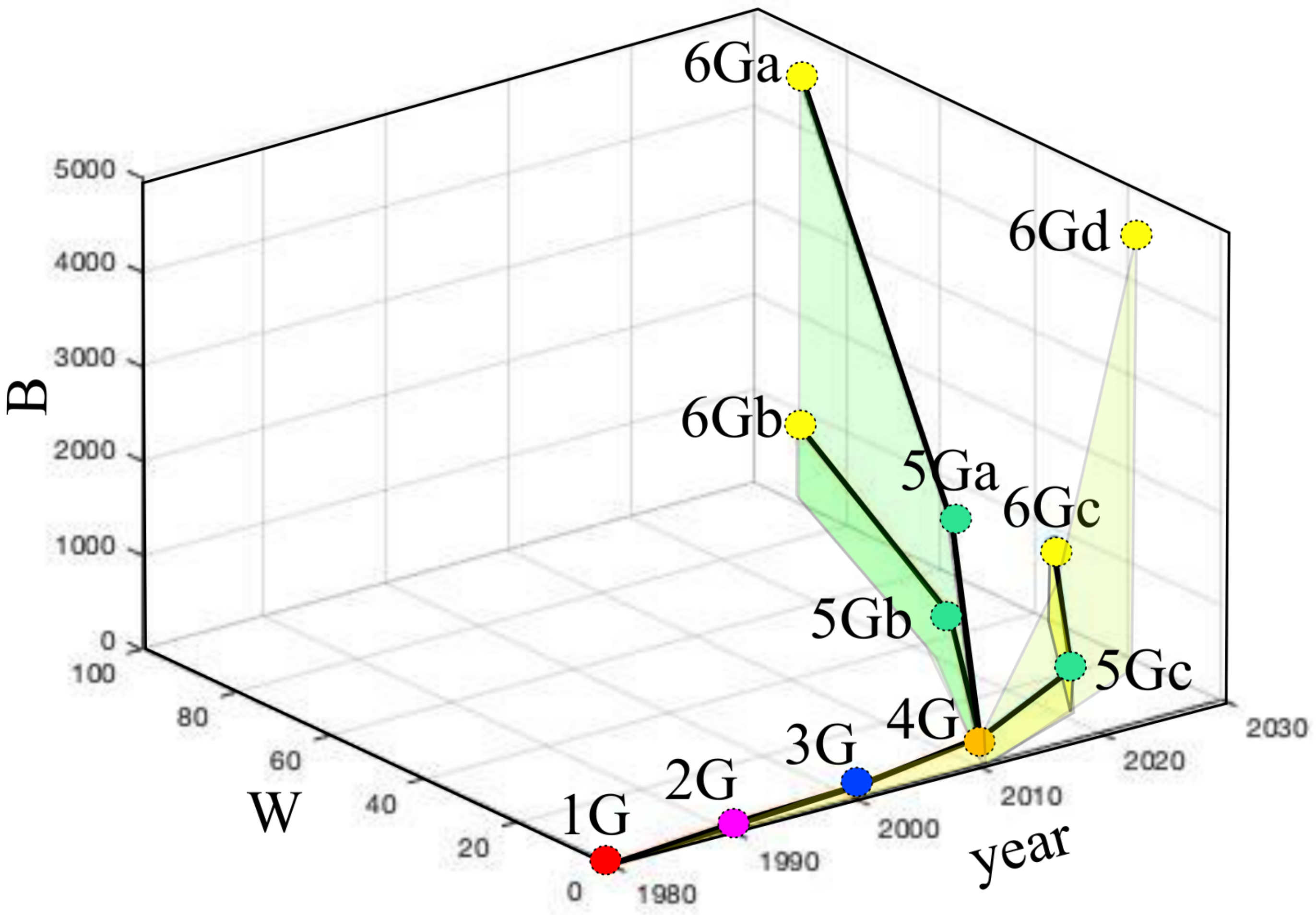
Number of Degrees of Freedom per unit time T and unit area **Ω**



Comments

- The figure shows the trend of the first 5 generations of cellular systems in terms of bandwidth B, spatial bandwidth W and approximative year of first deployment
- The position of 5G in this scheme depends on the choice of the operators; 5Ga is the most ambitious scenario, with an aggressive use of millimeter band and an optimal use of the spatial bandwidth; 5Gb refers to the same scenario of 5Gb but in a non millimeter cell; 5Gc and 5Gd scenario refer to a non millimeter cell and a millimeter cell that use the spatial resources in a suboptimal way.
- Note that the maximum number of layers currently used in FR1 5G is of the order of 16. This value matches with 5Gc

6G ?


6Ga
6Gd
6Gb
5Ga
6Gc
5Gb
5Gc
4G
3G
2G
1G
5000
4000
3000
2000
1000
0
B
100
80
60
40
20
0
W
1980
1990
2000
2010
2020
2030
year

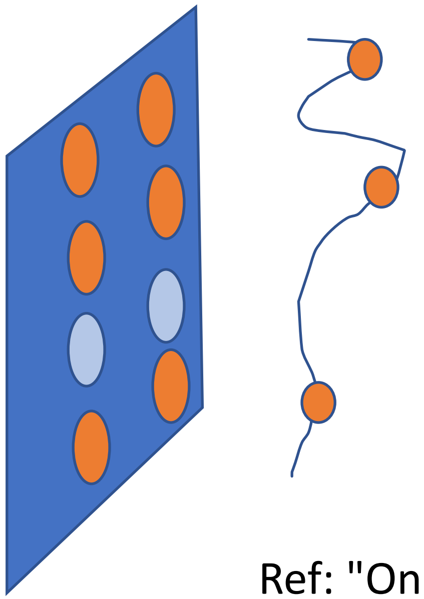
6G ? (comments)

- A projection toward 6G ; the position of 6G in this scheme depends on the choice of the operators;
- In particular 6Gc refers to a non millimeter cell that use **in an optimal way** the spatial resources offered by an array having a number of elements of the order of the elements of currently used FR1 5G mMIMO antennas;
- 6Gc suggests that there is still large space for improvement of B using a number of radiating elements of the same orde of the ones currently used in FR1 5G antennas

How to obtain a better use of the space resource ?

Equispaced arrays gives a large (spatial) oversampling of the field

Mathematically, we need to sample at the **(spatial) innovation rate of the field**



The density of the antenna elements must be higher in the area where the field has faster spatial variations [See Ref]

We need the equivalent to a non uniform sampling of a (spatial) function whose local (spatial) bandwidth is not constant

A simple example of suboptimal solution is the element selection method

Ref: "On the role of the number of degrees of freedom of the field in MIMO channels." *IEEE Transactions on Antennas and Propagation* , 2006

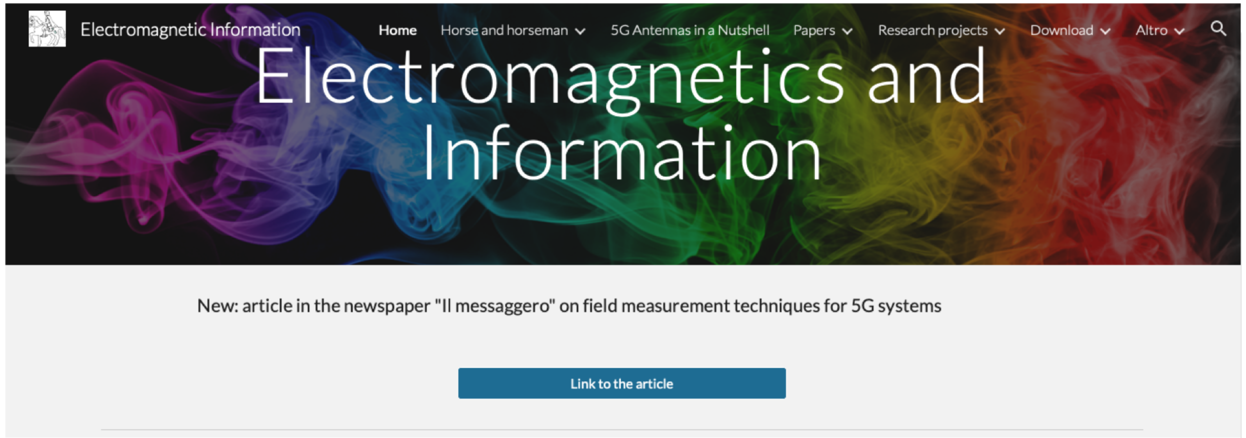
Conclusions

The developed of 5G according to the ‘less aggressive’ space-resource scenario currently adopted in deployed systems leaves space for a more efficient the use of the spatial bandwidth.

Taking this observation into consideration, 6G could be more focused toward the optimal use of the available space resources than toward an increase of the number of radiating elements.

According to this scenario the market will be still dominated by array antennas with a ‘moderate’ number of active elements (of the same order of currently deployed ‘Massive MIMO’ antennas’) but distributed on larger surfaces, eventually including a dynamical selection strategy.

Thank you for your attention



More information at the url

https://sites.google.com/unicas.it/electromagnetic-information/home

For any question you can contact the author at **mdmiglio@unicas.it**