Universitat Pompeu Fabra Barcelona

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Angel Lozano

Post-Cellular Wireless Networks

Outline

① Flashback

② Coming Up: 5G

③ A World Without Cells?

① Flashback

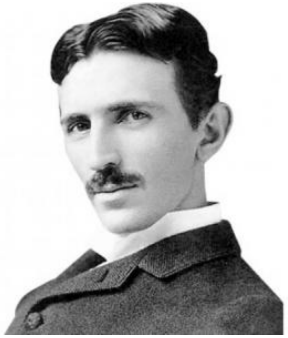
1st Breakthrough

James C. Maxwell

Heinrich Hertz

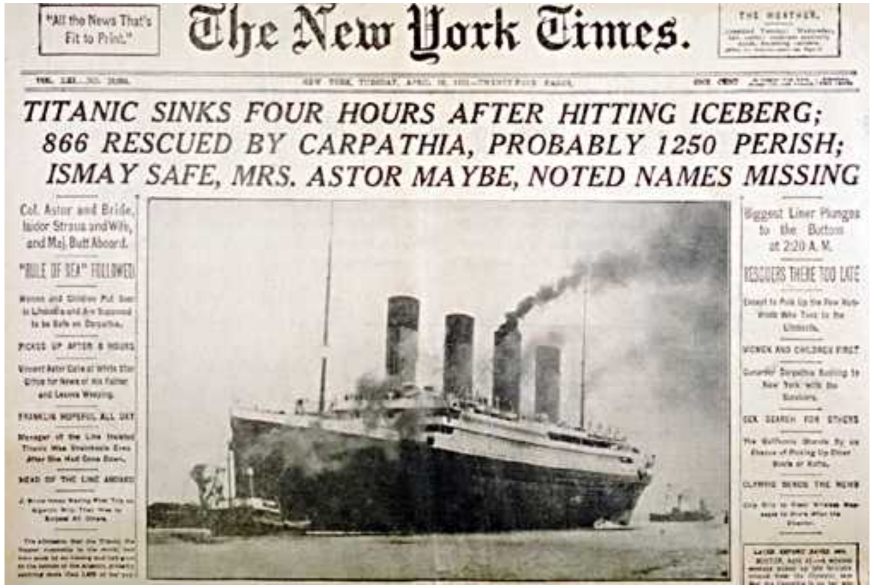
"I do not think that the wireless waves I have discovered will have any practical applications"

2nd Breakthrough



Nikola Tesla

Guglielmo Marconi



"All the News That's Fit to Print."

The New York Times.

TITANIC SINKS FOUR HOURS AFTER HITTING ICEBERG;
866 RESCUED BY CARPATHIA, PROBABLY 1250 PERISH;
ISMAY SAFE, MRS. ASTOR MAYBE, NOTED NAMES MISSING

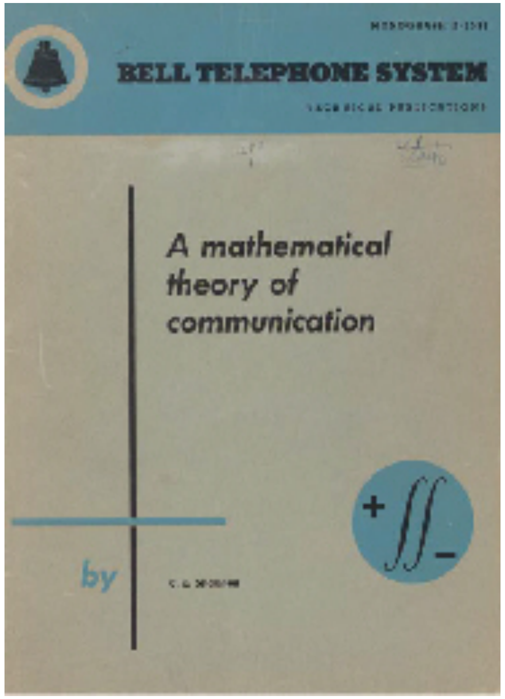
Col. Astor and Bride, Isidor Straus and Wife, and Maj. Butt Aboard.

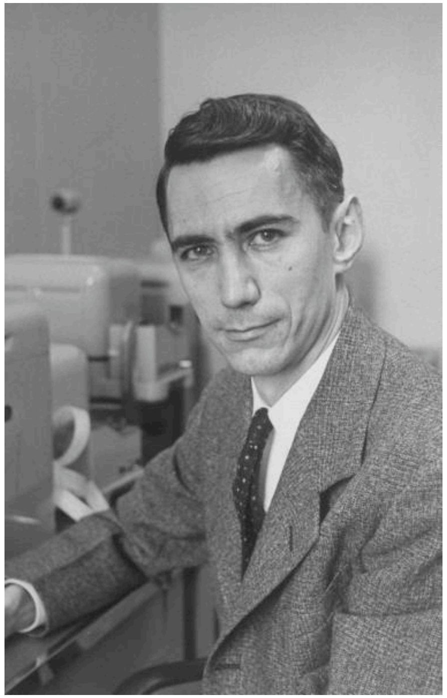
"RULE OF SEA" FOLLOWED

Biggest Liner Plunges to the Bottom at 2:20 A. M.

RESCUERS THERE TOO LATE

4th Breakthrough



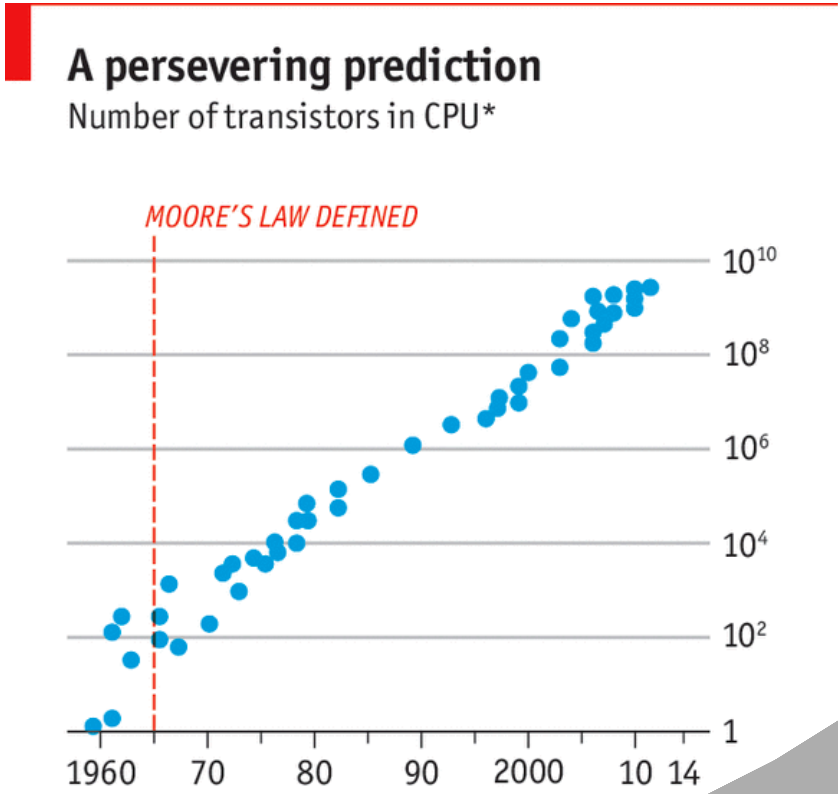


Claude Shannon

Bell Laboratories

5^{th} Breakthrough

"There's plenty of room at the bottom"
R. Feynman

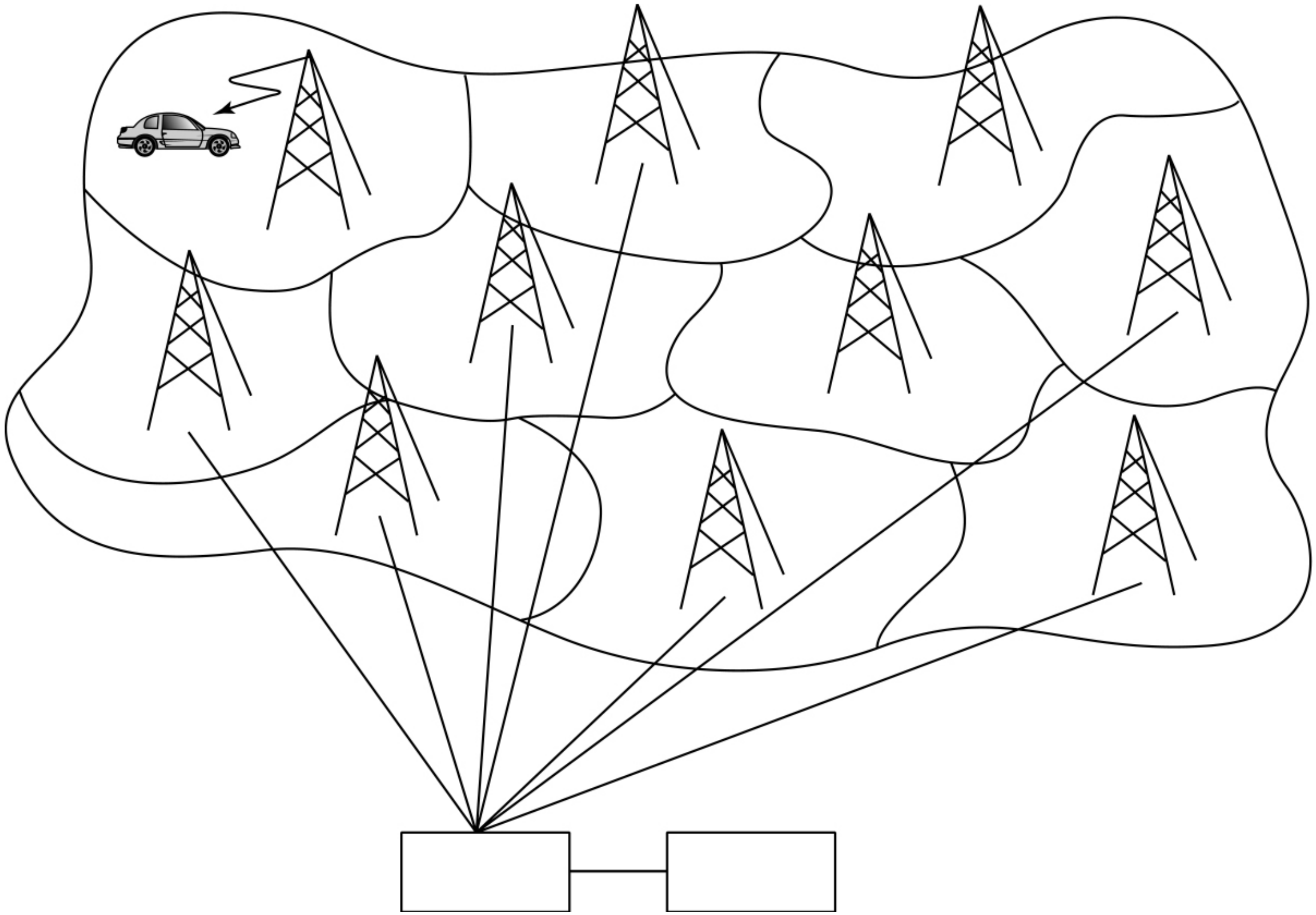


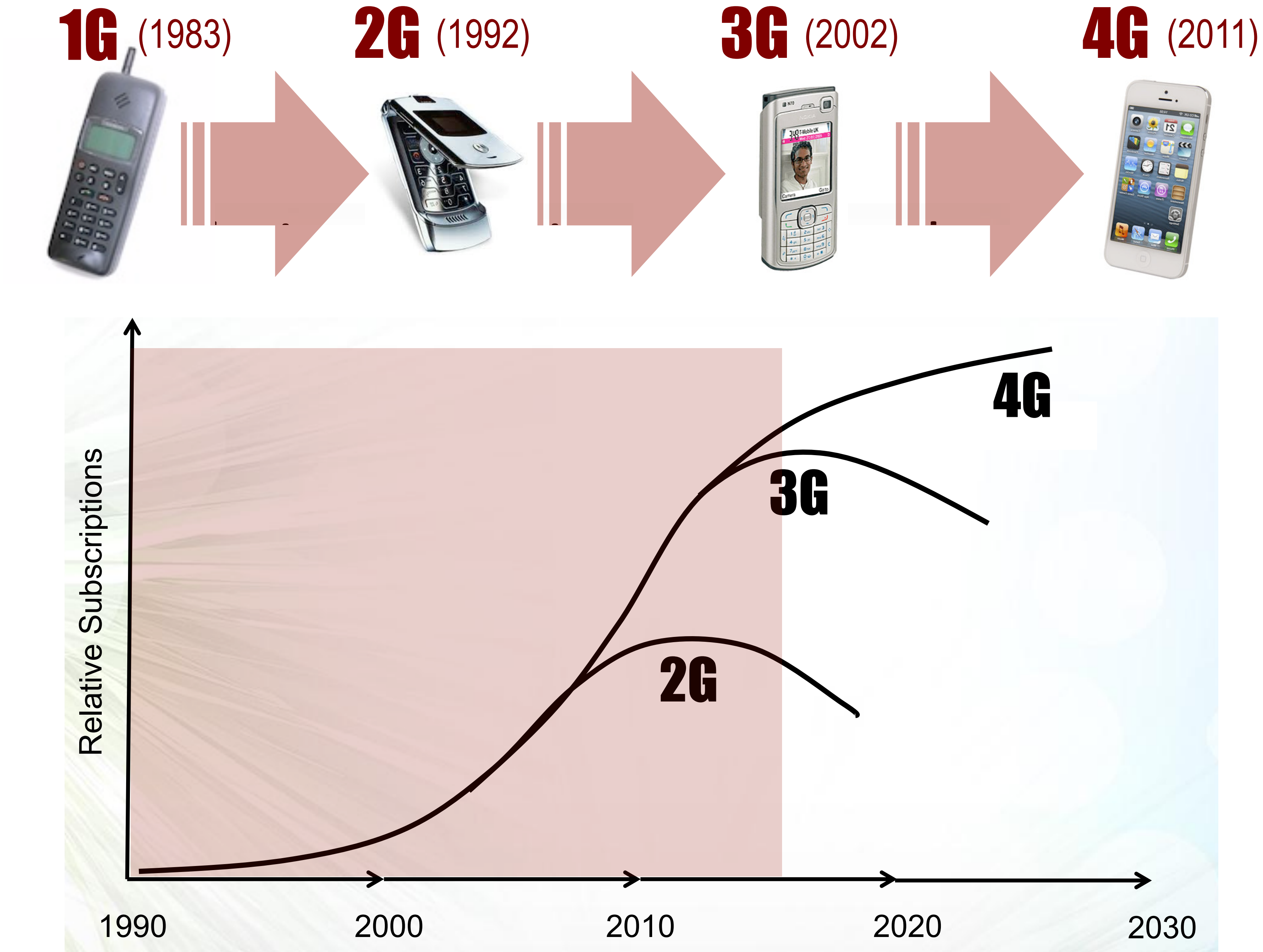
Cellular Service Trial — Chicago

Figure 3. *Coverage maps for the Chicago and Newark trials.*

Martin
Cooper

① Flashback




1G (1983)
2G (1992)
3G (2002)
4G (2011)
Relative Subscriptions
4G
3G
2G
1990
2000
2010
2020
2030

① Flashback

Area Capacity

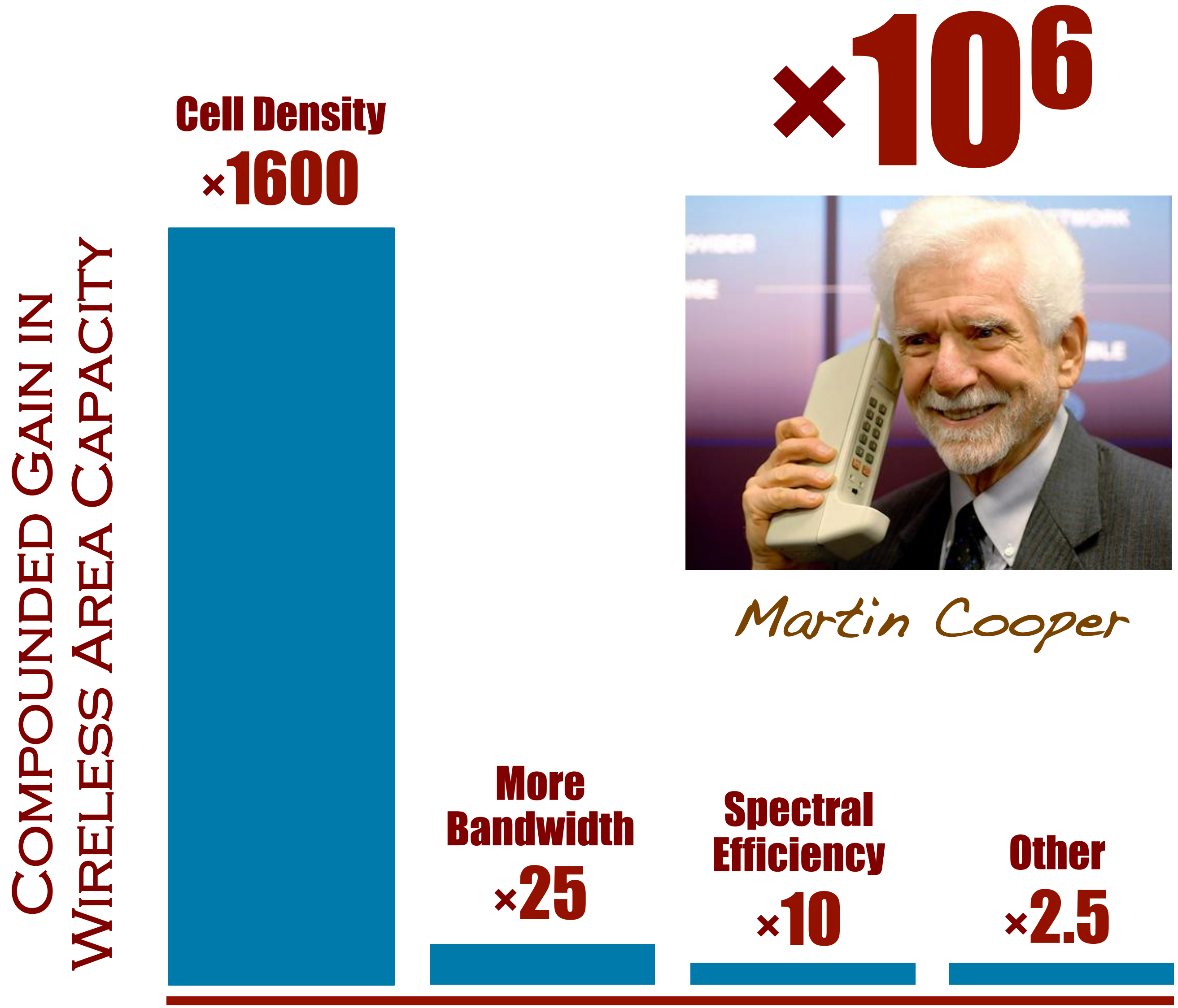
$$\left[\frac{\text{bits/s}}{\text{Km}^2}\right] = \left[\frac{\text{bits/s/Hz}}{\text{cell}}\right] \cdot \left[\frac{\text{cell}}{\text{Km}^2}\right] \cdot [\text{Hz}]$$

Spectral Efficiency

Cell Density

Bandwidth

① Flashback


×10^6
Martin Cooper
Compounded Gain in Wireless Area Capacity
Cell Density
×1600
More Bandwidth
×25
Spectral Efficiency
×10
Other
×2.5

Area Capacity

$$\left[\frac{\text{bits/s}}{\text{Km}^2}\right] = \left[\frac{\text{bits/s/Hz}}{\text{cell}}\right] \cdot \left[\frac{\text{cell}}{\text{Km}^2}\right] \cdot [\text{Hz}]$$

$$\approx 1\,\frac{\text{b/s/Hz}}{\text{cell}} \cdot \frac{\text{cell}}{1000\ \text{users}} \cdot 500\ \text{MHz}$$

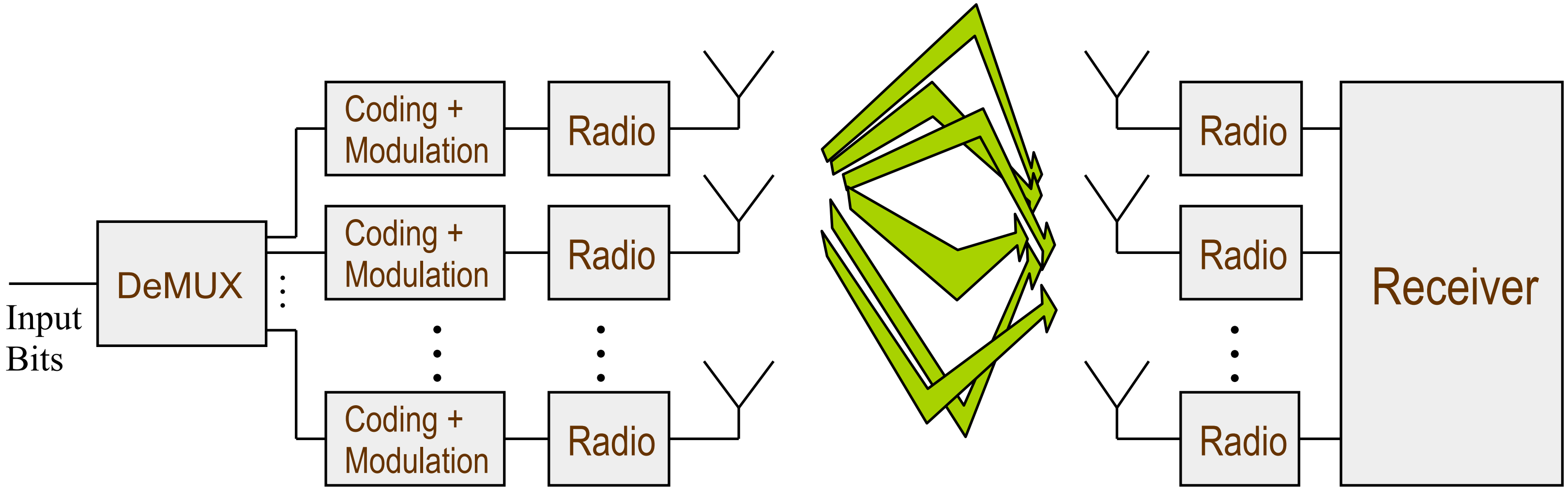
Spectral Efficiency

Cell Density

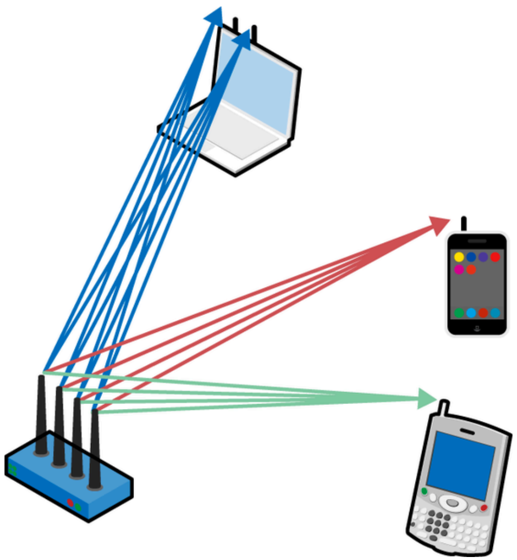
Bandwidth

$$= 500\,\frac{\text{Kb/s}}{\text{user}}$$

MIMO (Multiple-Input Multiple-Output)

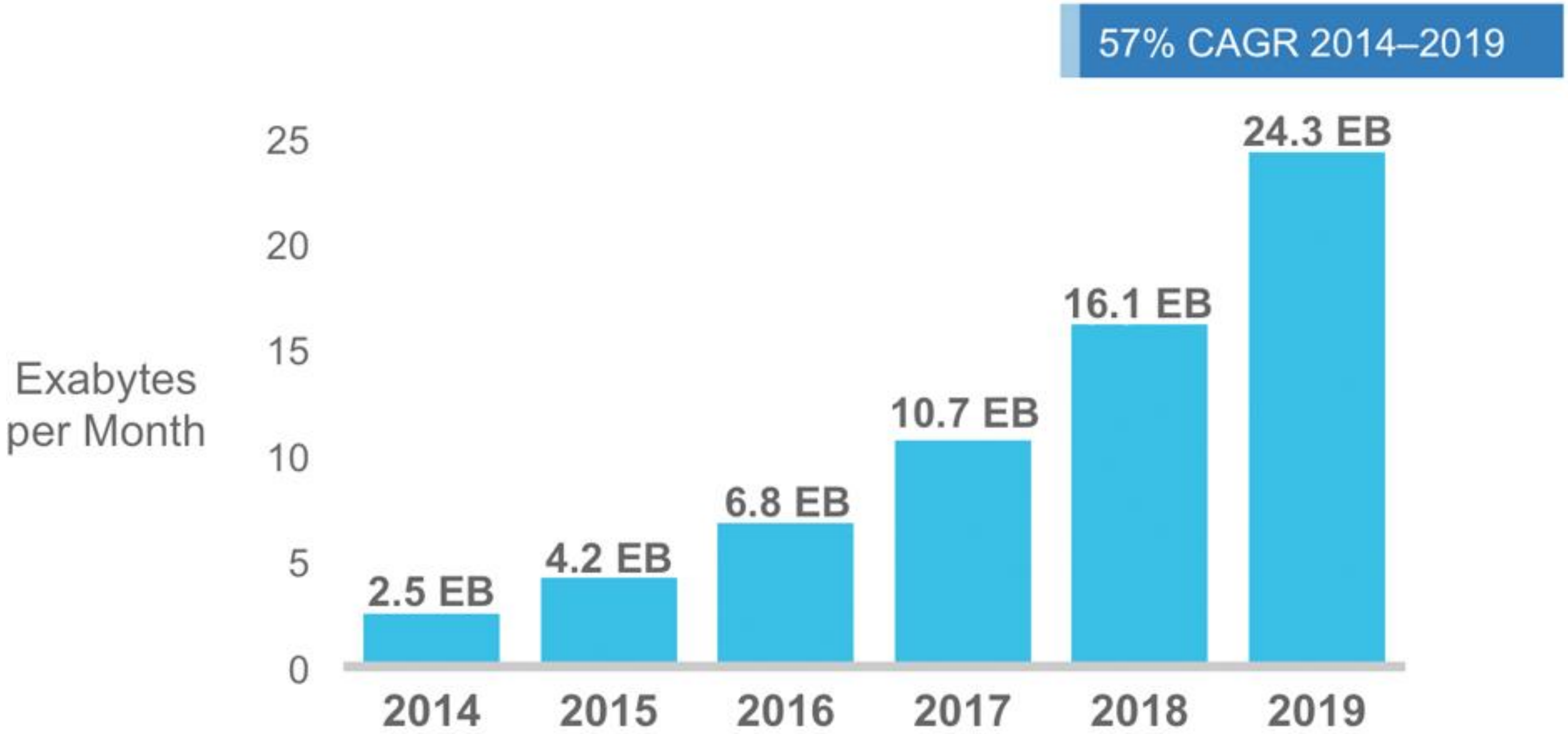


$$y = Hx + n$$



② Coming Up: 5G

④ Coming Up: 5G



④ Coming Up: 5G

What Will 5G Be?

Jeffrey G. Andrews, *Fellow, IEEE*, Stefano Buzzi, *Senior Member, IEEE*, Wan Choi, *Senior Member, IEEE*, Stephen V. Hanly, *Member, IEEE*, Angel Lozano, *Fellow, IEEE*, Anthony C. K. Soong, *Fellow, IEEE*, and Jianzhong Charlie Zhang, *Senior Member, IEEE*

***Abstract*—What will 5G be? What it will *not* be is an incremental advance on 4G. The previous four generations of cellular technology have each been a major paradigm shift that has broken backward compatibility. Indeed, 5G will need to be a paradigm shift that includes very high carrier frequencies with massive bandwidths, extreme base station and device densities, and unprecedented numbers of antennas. However, unlike the previous four generations, it will also be highly integrative: tying any new 5G air interface and spectrum together with LTE and WiFi to provide universal high-rate coverage and a seamless user experience. To support this, the core network will also have to reach unprecedented levels of flexibility and intelligence, spectrum regulation will need to be rethought and improved, and energy and cost efficiencies will become even more critical considerations. This paper discusses all of these topics, identifying key challenges for future research and preliminary 5G standardization activities, while providing a comprehensive overview of the current literature, and in particular of the papers appearing in this special issue.**

***Index Terms*—Cellular systems, energy efficiency, HetNets, massive MIMO, millimeter wave, small cells.**

I. Introduction

A. The Road to 5G

IN just the past year, preliminary interest and discussions about a possible 5G standard have evolved into a full-released by Cisco, we have quantitative evidence that the wireless data explosion is real and will continue. Driven largely by smartphones, tablets, and video streaming, the most recent (Feb. 2014) VNI report [2] and forecast makes plain that an incremental approach will not come close to meeting the demands that networks will face by 2020.

In just a decade, the amount of IP data handled by wireless networks will have increased by well over a factor of 100: from under 3 exabytes in 2010 to over 190 exabytes by 2018, on pace to exceed 500 exabytes by 2020. This deluge of data has been driven chiefly by video thus far, but new unforeseen applications can reasonably be expected to materialize by 2020. In addition to the sheer volume of data, the number of devices and the data rates will continue to grow exponentially. The number of devices could reach the tens or even hundreds of billions by the time 5G comes to fruition, due to many new applications beyond personal communications [3]–[5]. It is our duty as engineers to meet these intense demands via innovative new technologies that are smart and efficient yet grounded in reality. Academia is engaging in collaborative projects such as METIS [6] and 5GNOW [7], while industry is driving preliminary 5G standardization activities (cf. Section IV-B). To further strengthen these activities, the public-private partnership

④ Coming Up: 5G

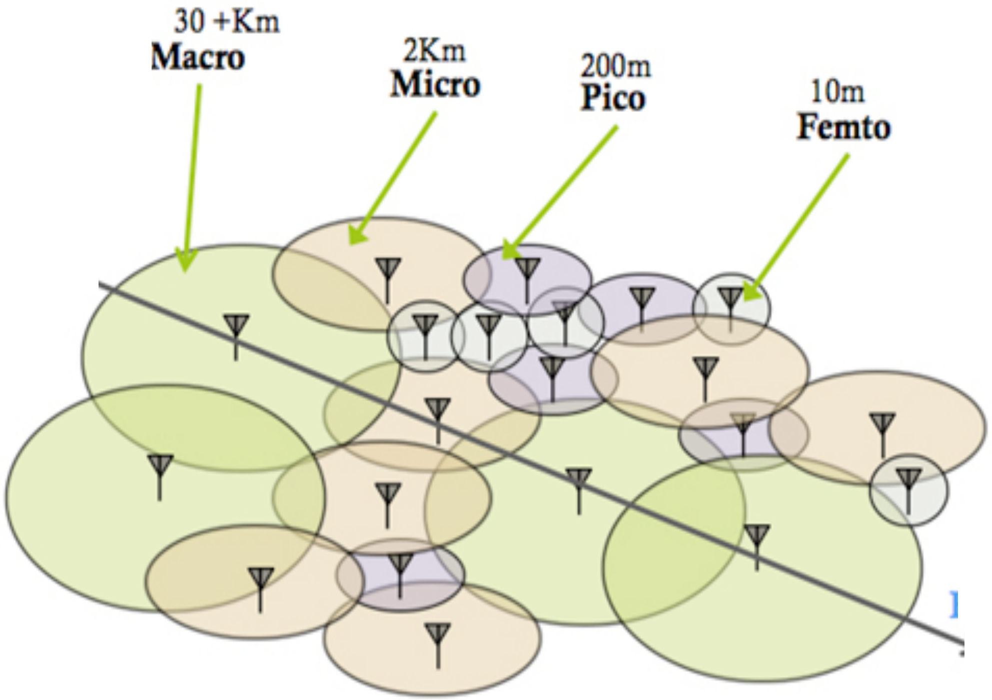
$$\left[\frac{\text{bits/s}}{\text{Km}^2}\right] = \left[\frac{\text{bits/s/Hz}}{\text{cell}}\right] \cdot \left[\frac{\text{cell}}{\text{Km}^2}\right] \cdot [\text{Hz}]$$

Spectral Efficiency → Massive MIMO

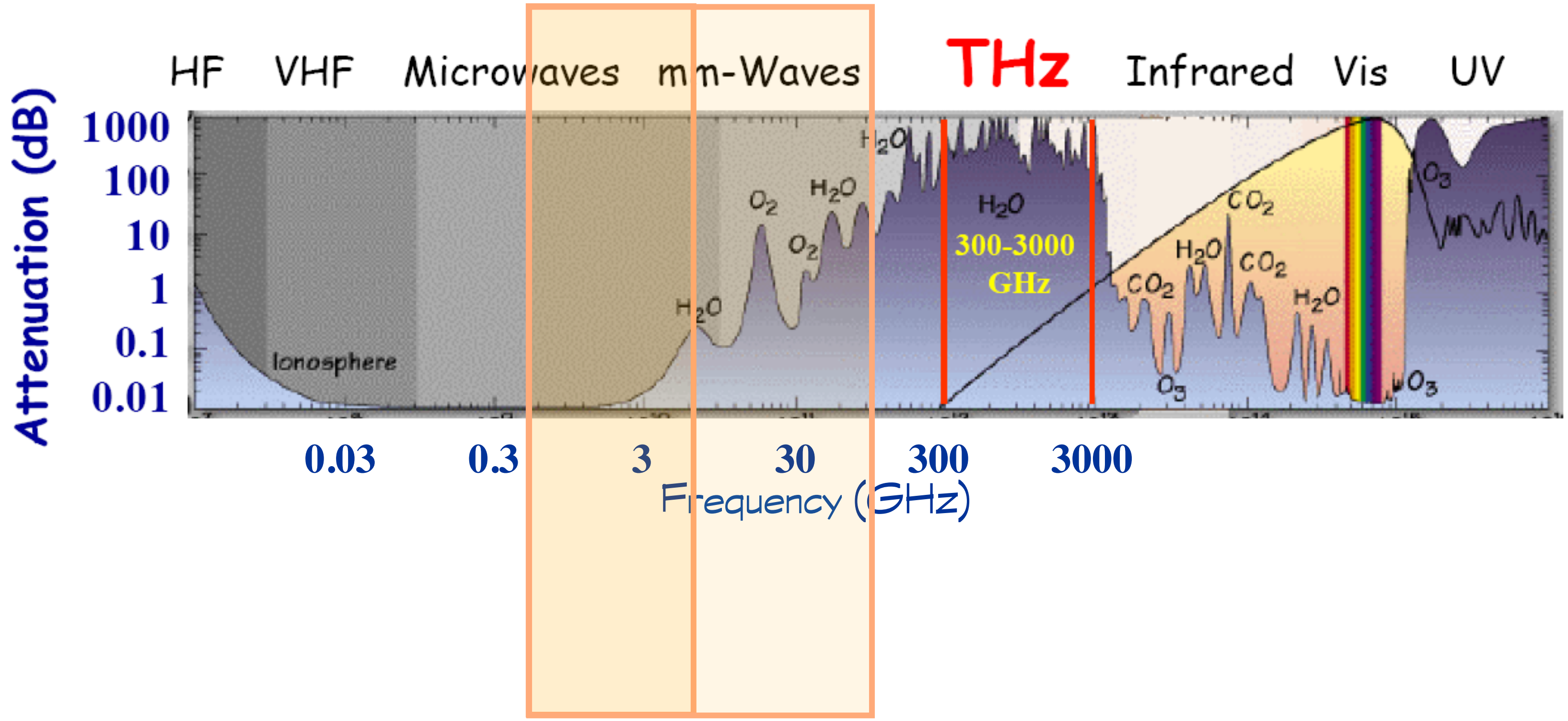
Densification → Ultra Densification

Bandwidth → New Spectrum

④ Coming Up: 5G



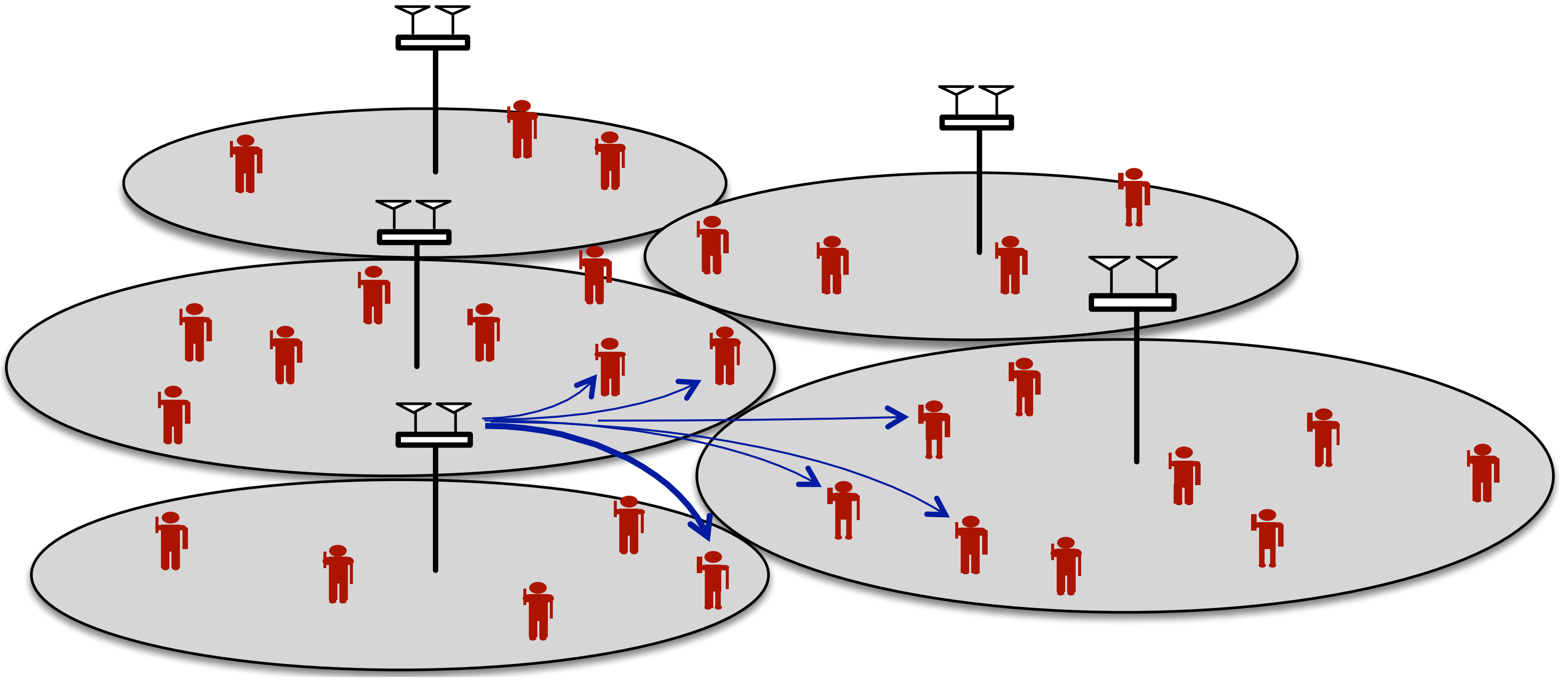
④ Coming Up: 5G



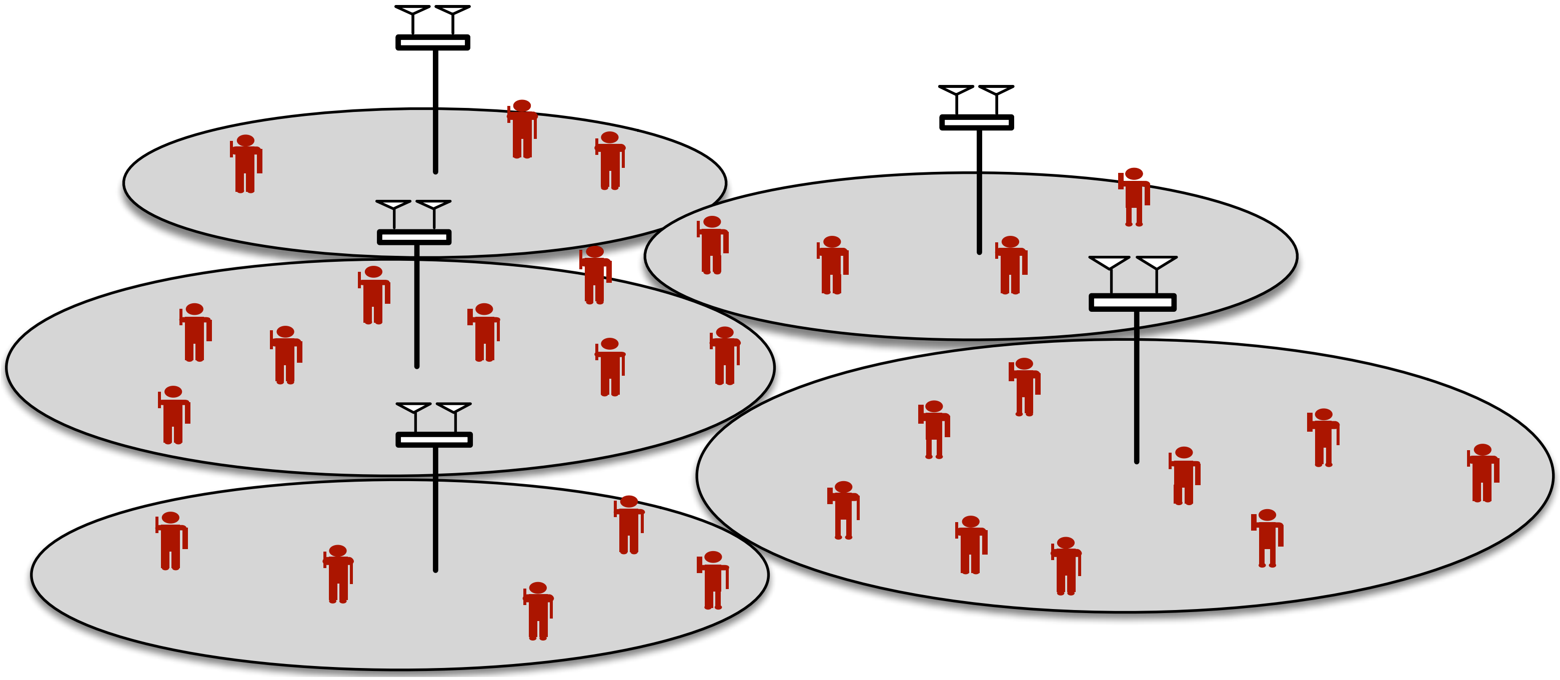
New spectrum enabled by ultradensification

③ A World Without Cells?

⑤ A World Without Cells?



⑤ A World Without Cells?



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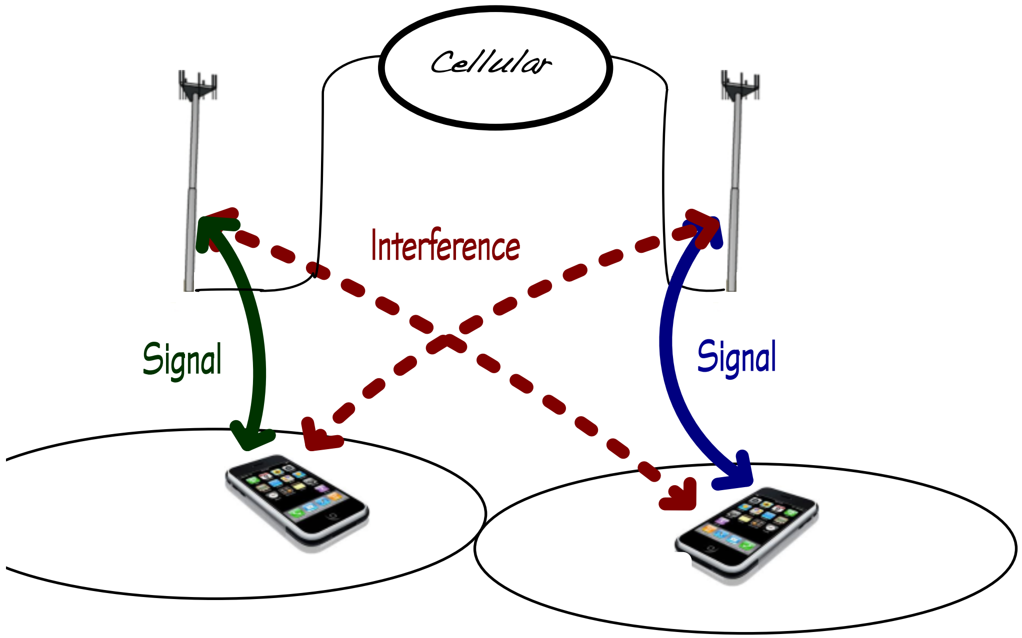

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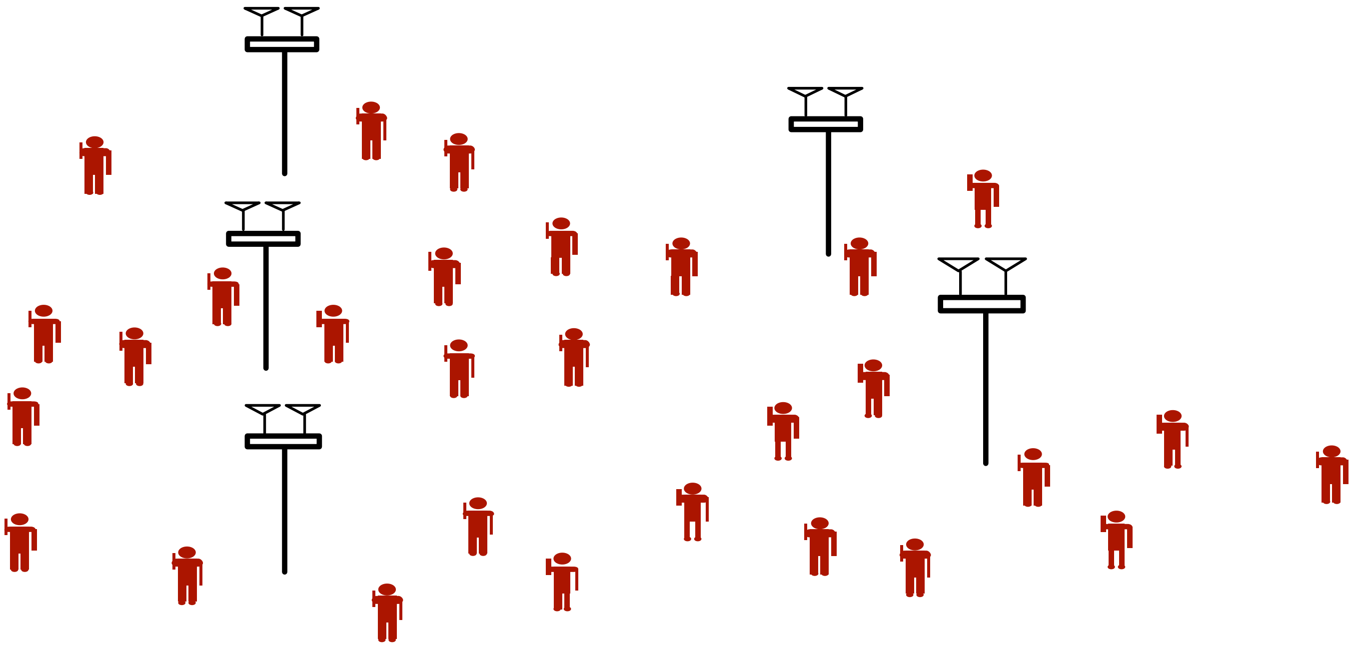

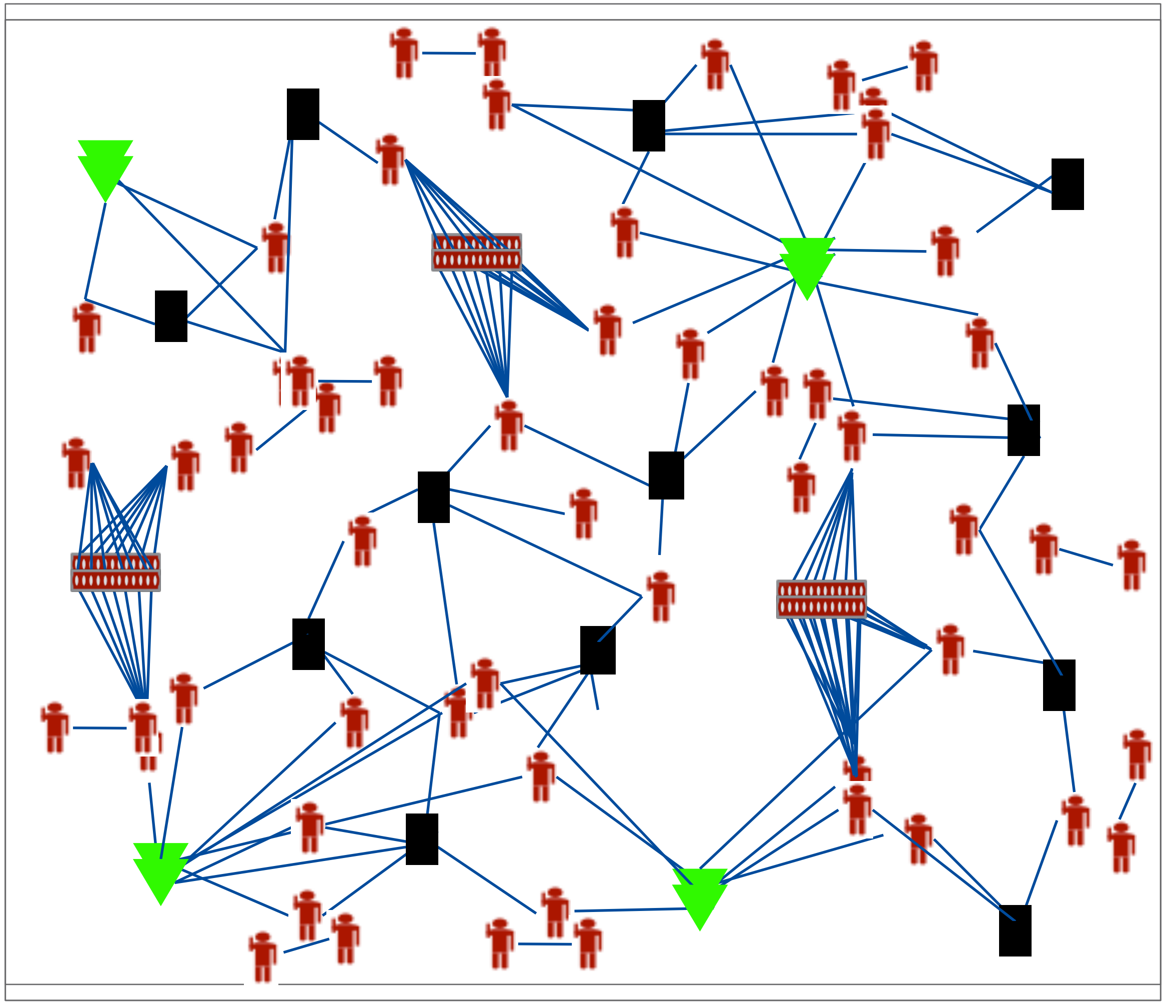

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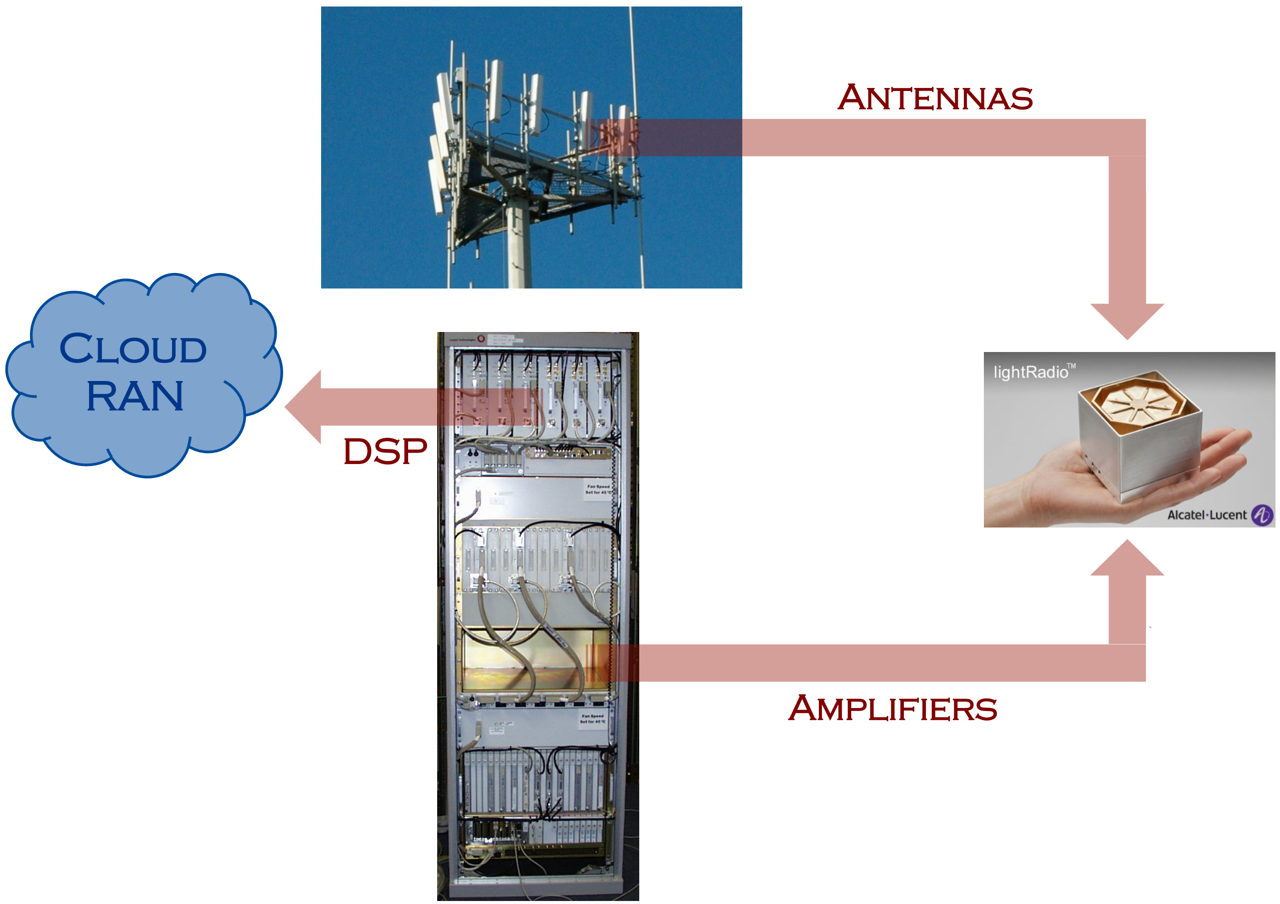
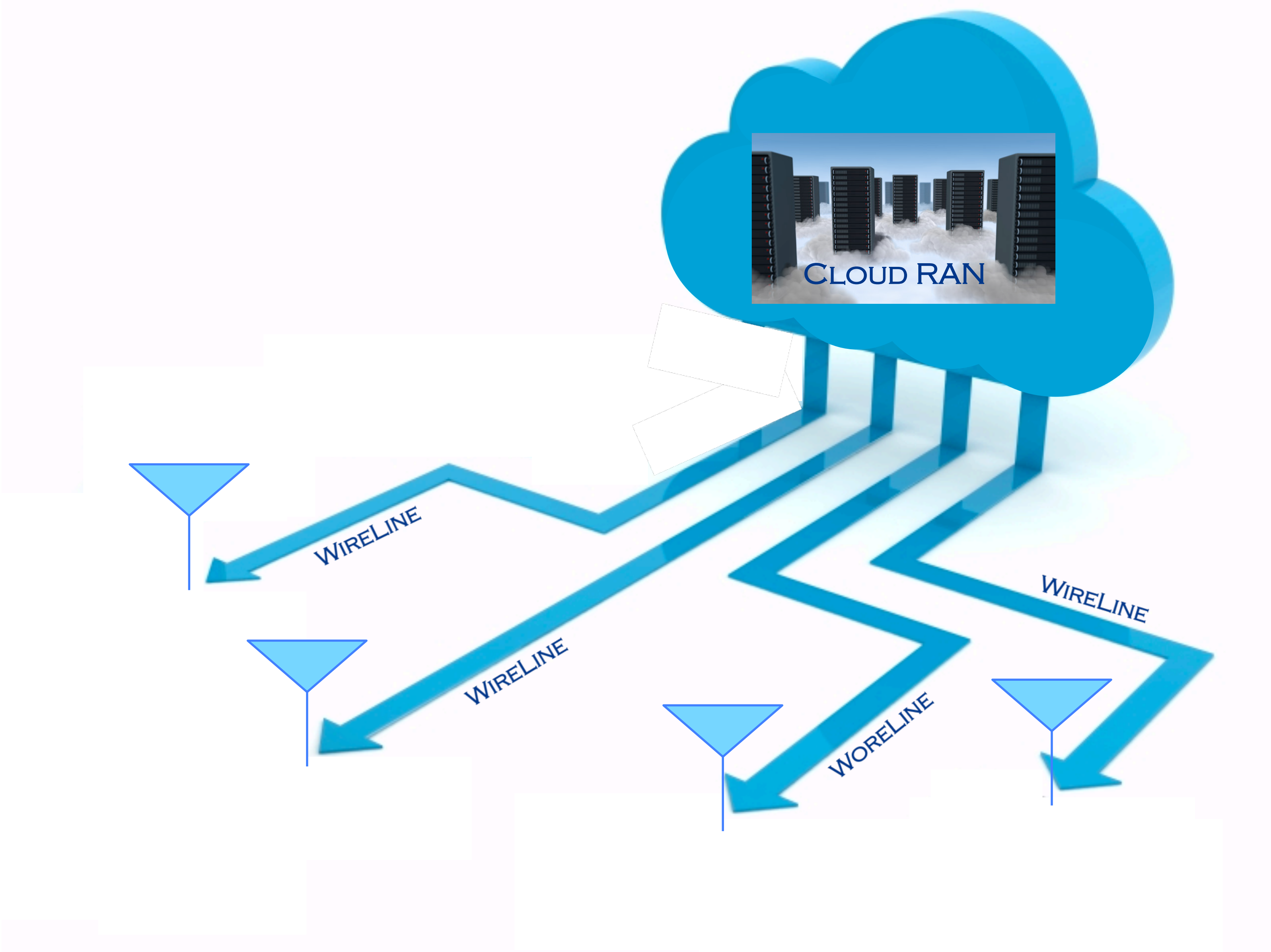


⑤ A World Without Cells?



“It’s dangerous to put limits on wireless”

Guglielmo Marconi, 1932