The Future of 5G

Muriel Médard

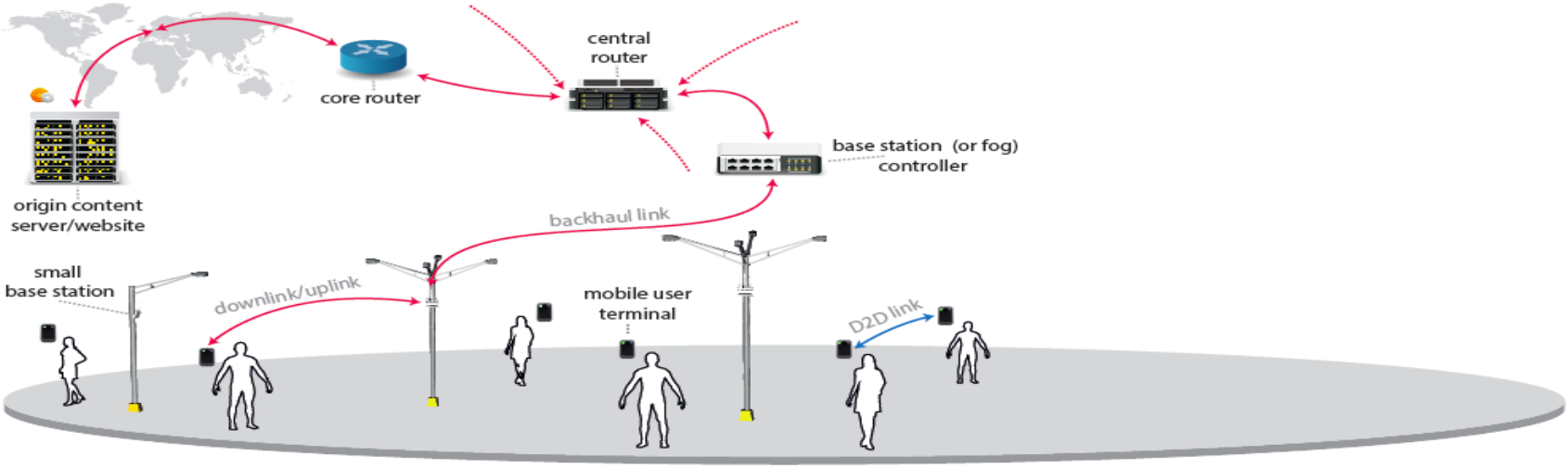
Cecil H. Green Professor of Electrical Engineering and Computer Science

Network Coding and Reliable Communications Group

Research Laboratory for Electronics

Massachusetts Institute of Technology.

The evolution



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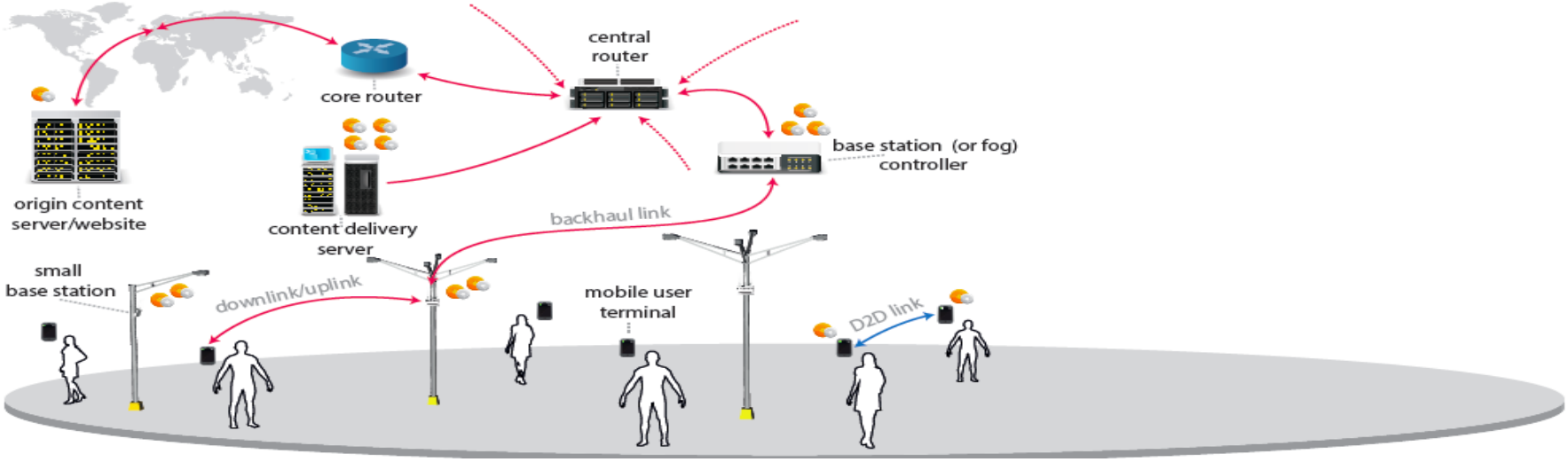
The evolution



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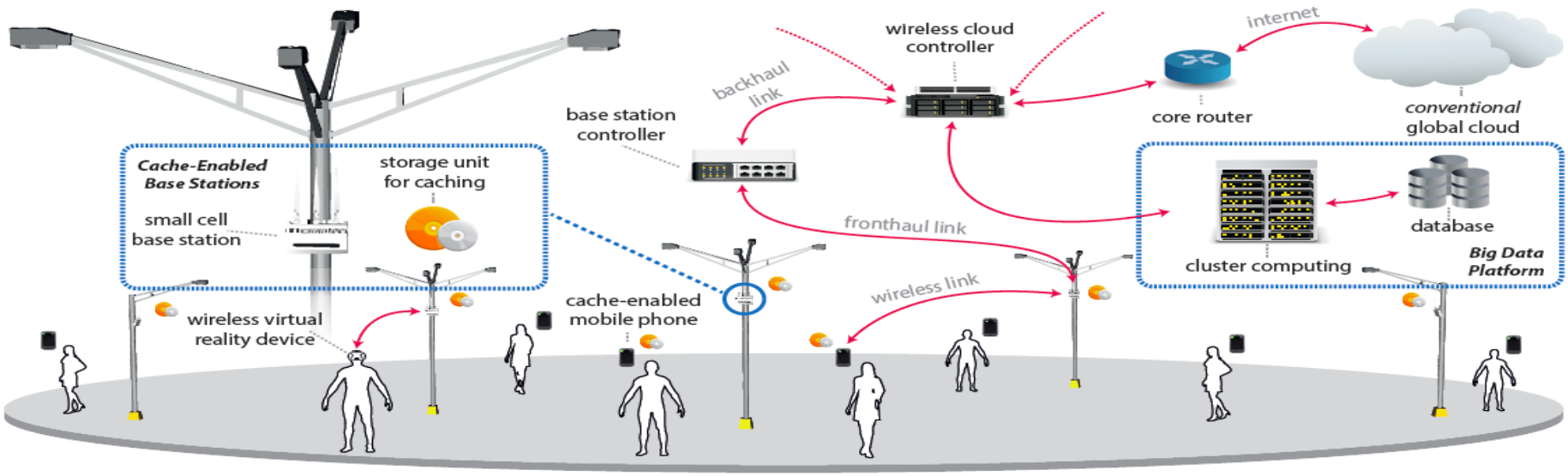

What is 5G?

- Formally:
  - Standardized technologies
- Informally:
  - Enabling ubiquitous communications
    - Integrated across technologies
    - Reliably
    - With low delay

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So what is different?

- Current jumble:
  - 4G (or initial 5G)
  - **WiFi**
  - Enterprise
  - IoT
  - Satellite
  - V2X

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5G seeks to unify

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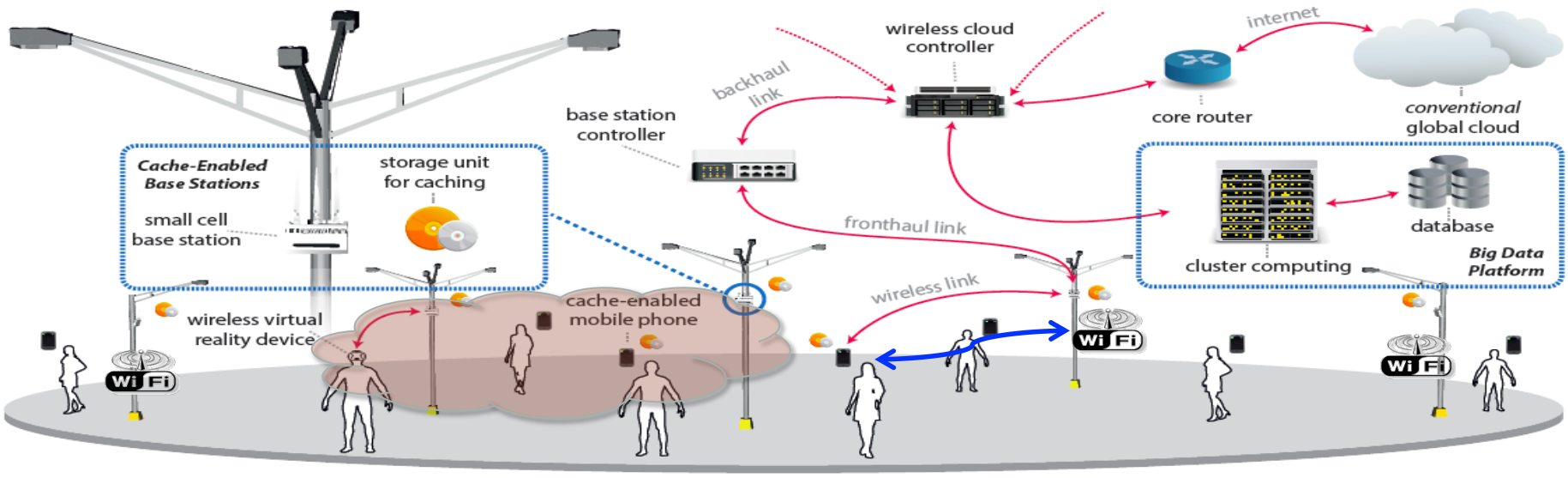

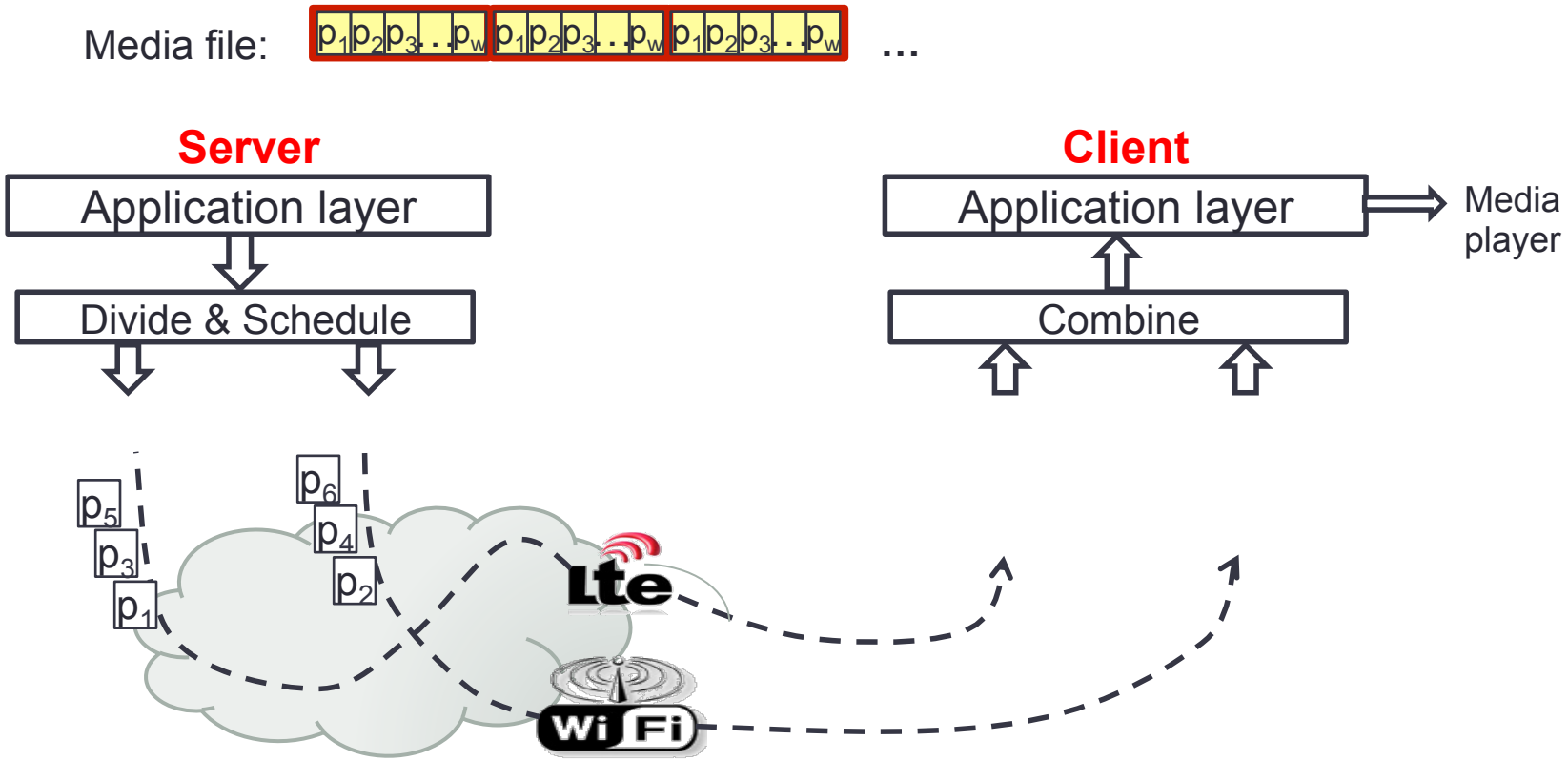
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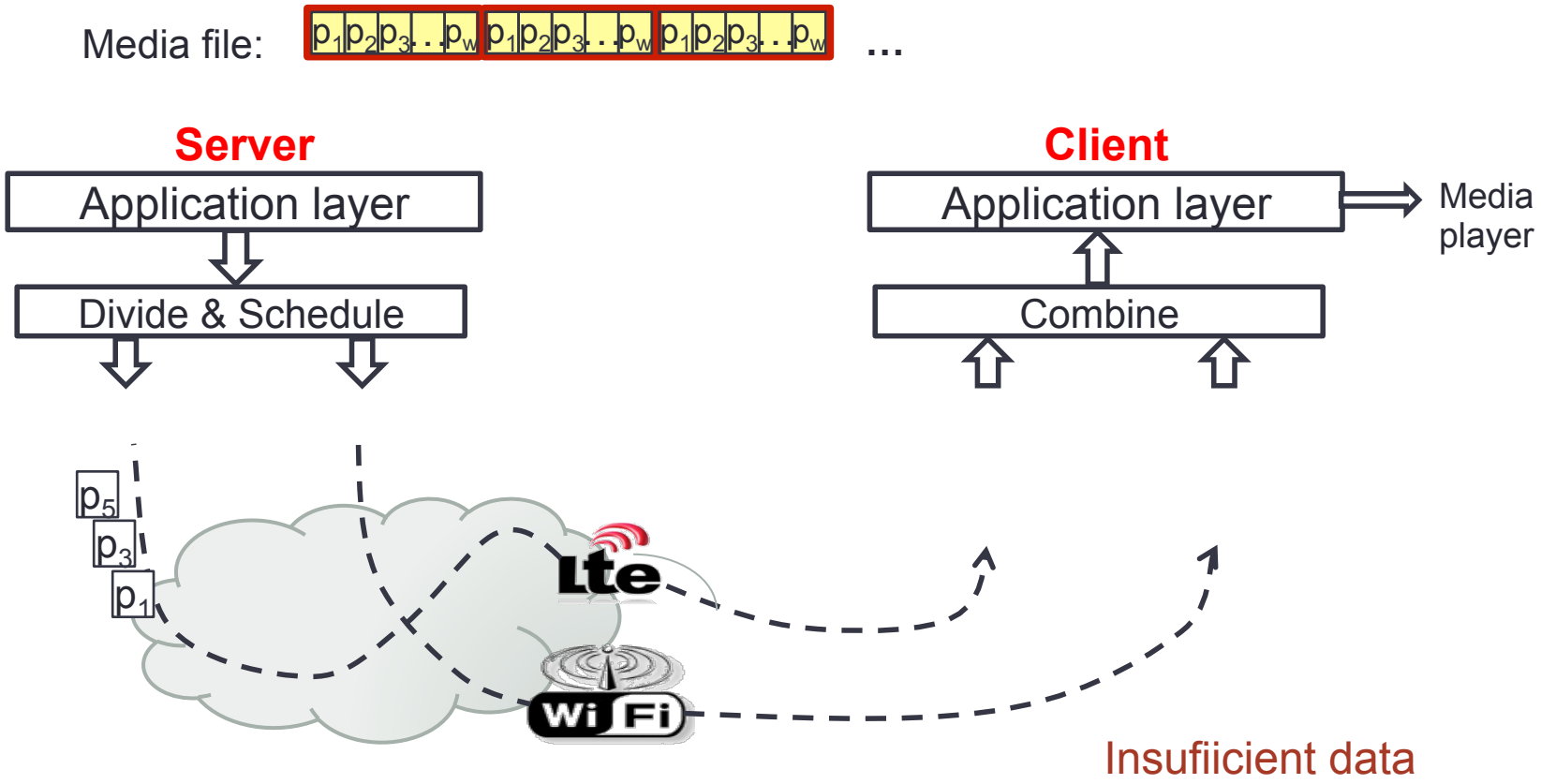
p1 p2 p3 . . pw p1 p2 p3 . . pw p1 p2 p3 . . pw ...
Server
Application layer
Divide & Schedule
Client
Application layer
Media player
Combine
p5 p3 p1
p6 p4 p2
Lte
Wi Fi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Server
Application layer
Divide & Schedule
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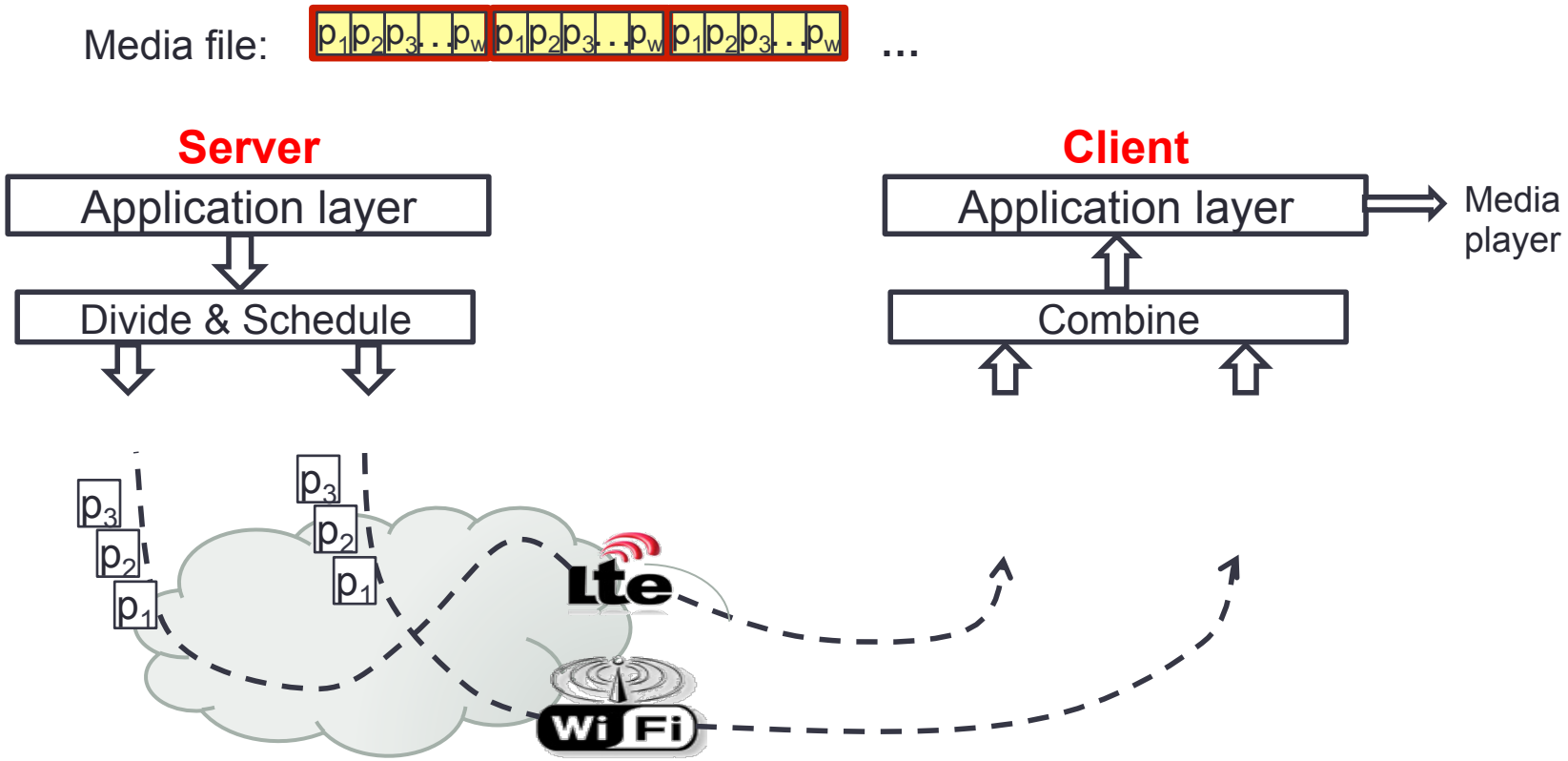
Application layer
Media player
Combine
p5
p3
p1
Lte
Wi Fi
Insufiicient data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...
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p3
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p1
p3
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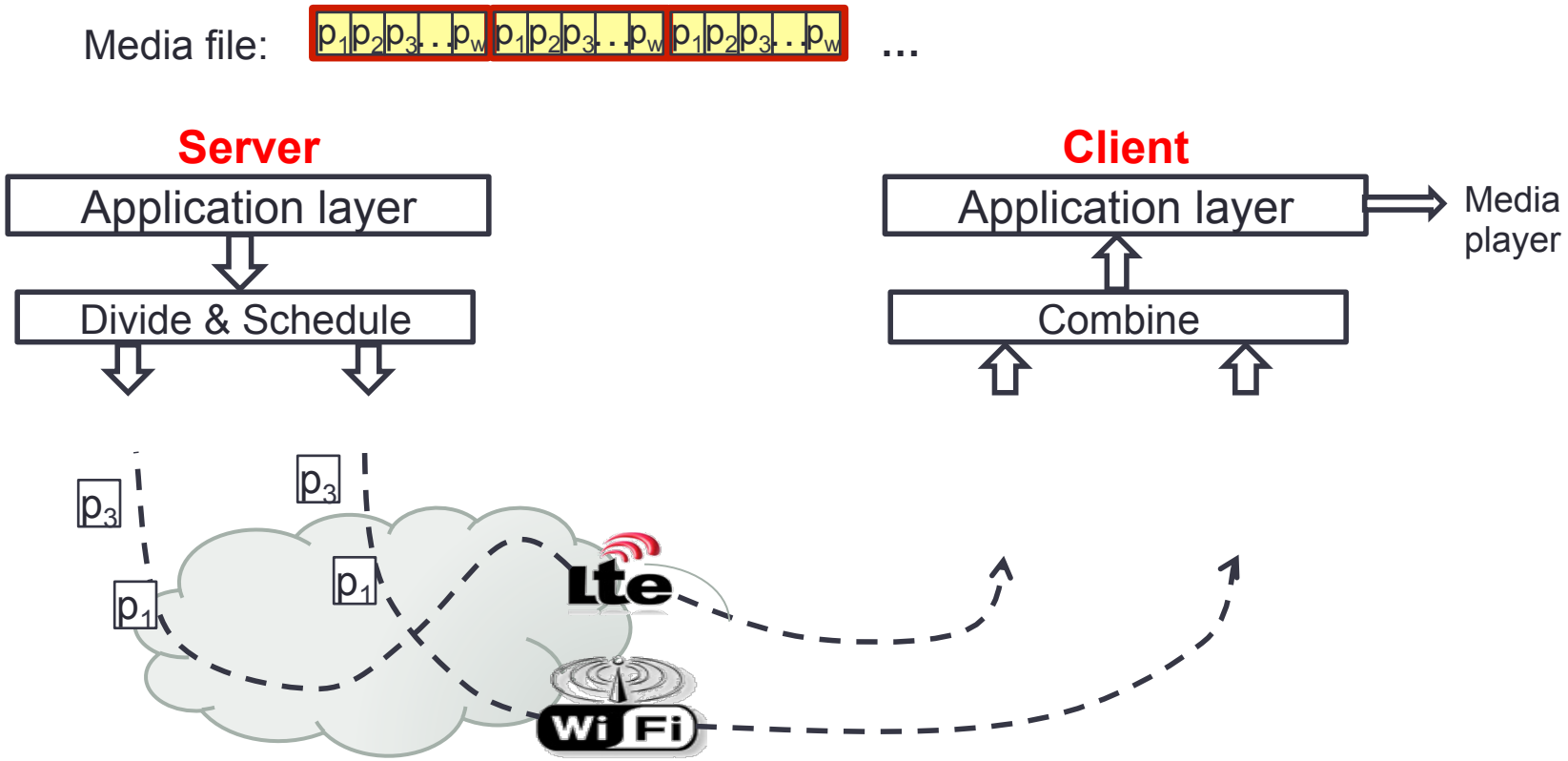
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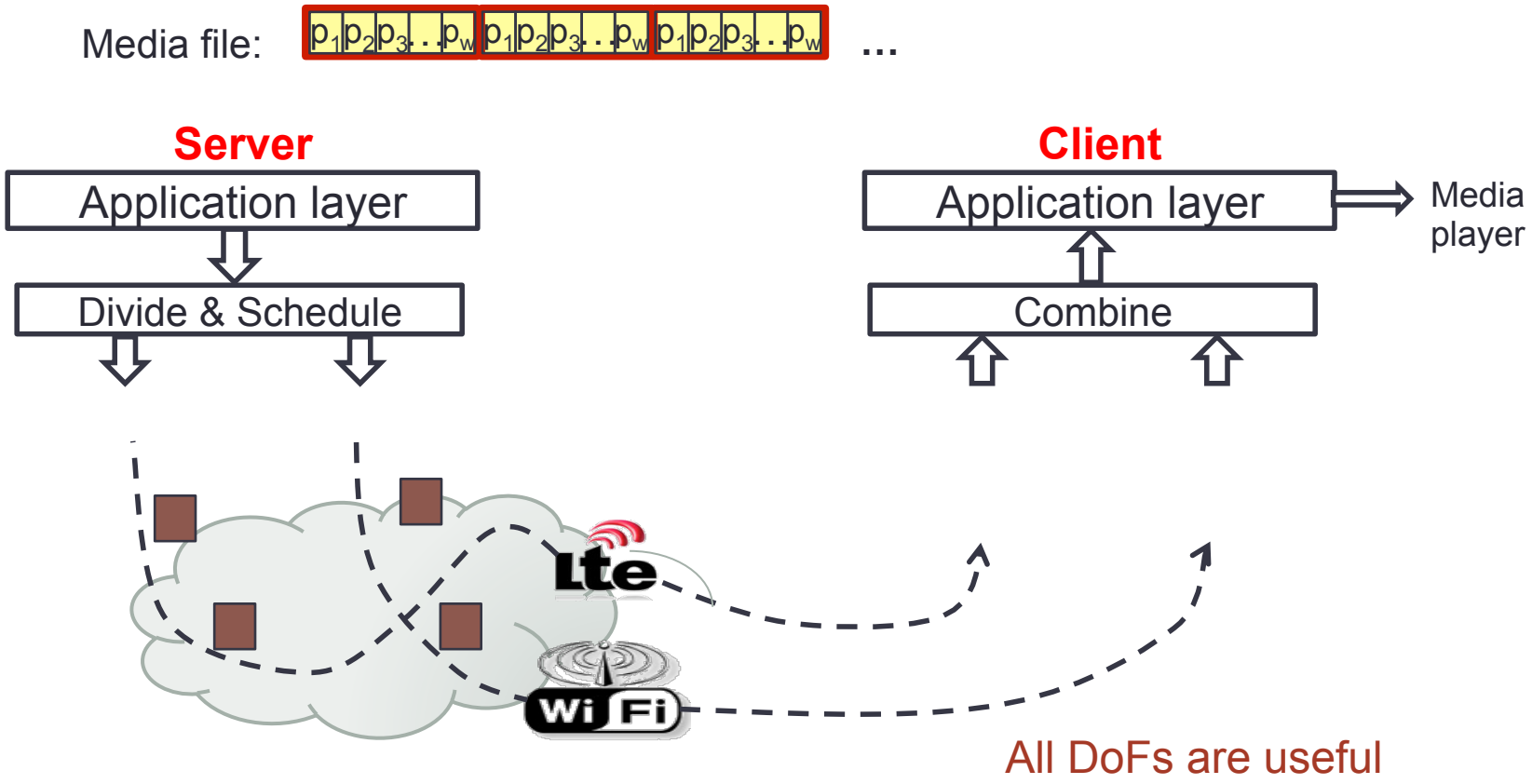
Media file:
p1 p2 p3 . . . pw p1 p2 p3 . . . pw p1 p2 p3 . . . pw
...
Server
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Application layer
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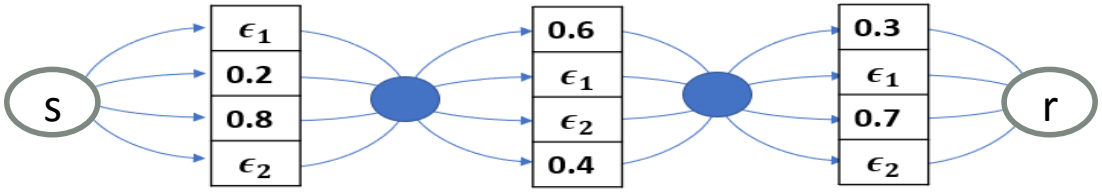
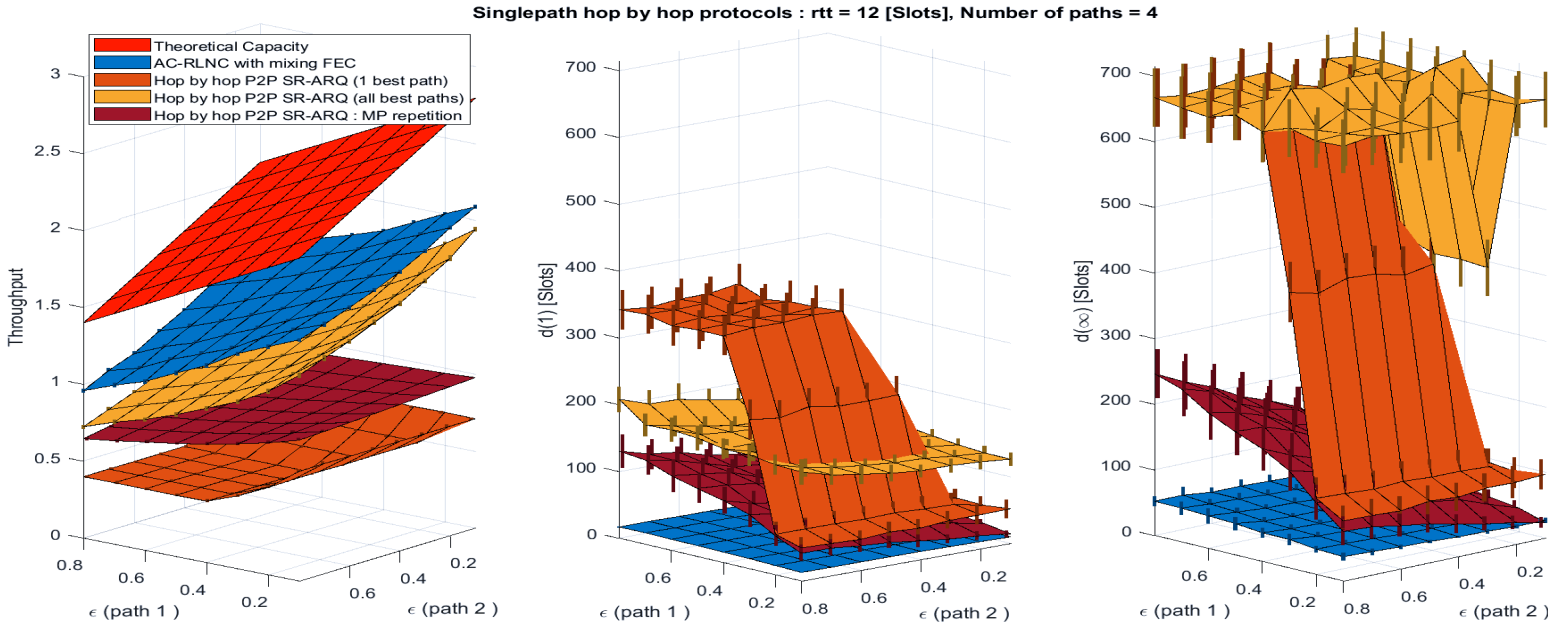
Lte
Wi Fi
All DoFs are useful

Mesh


s
ϵ_1
0.2
0.8
ϵ_2
0.6
ϵ_1
ϵ_2
0.4
0.3
ϵ_1
0.7
ϵ_2
r


Singlepath hop by hop protocols : rtt = 12 [Slots], Number of paths = 4
Theoretical Capacity
AC-RLNC with mixing FEC
Hop by hop P2P SR-ARQ (1 best path)
Hop by hop P2P SR-ARQ (all best paths)
Hop by hop P2P SR-ARQ : MP repetition
Throughput
d(1) [Slots]
d(∞) [Slots]
ϵ (path 1)
ϵ (path 2)

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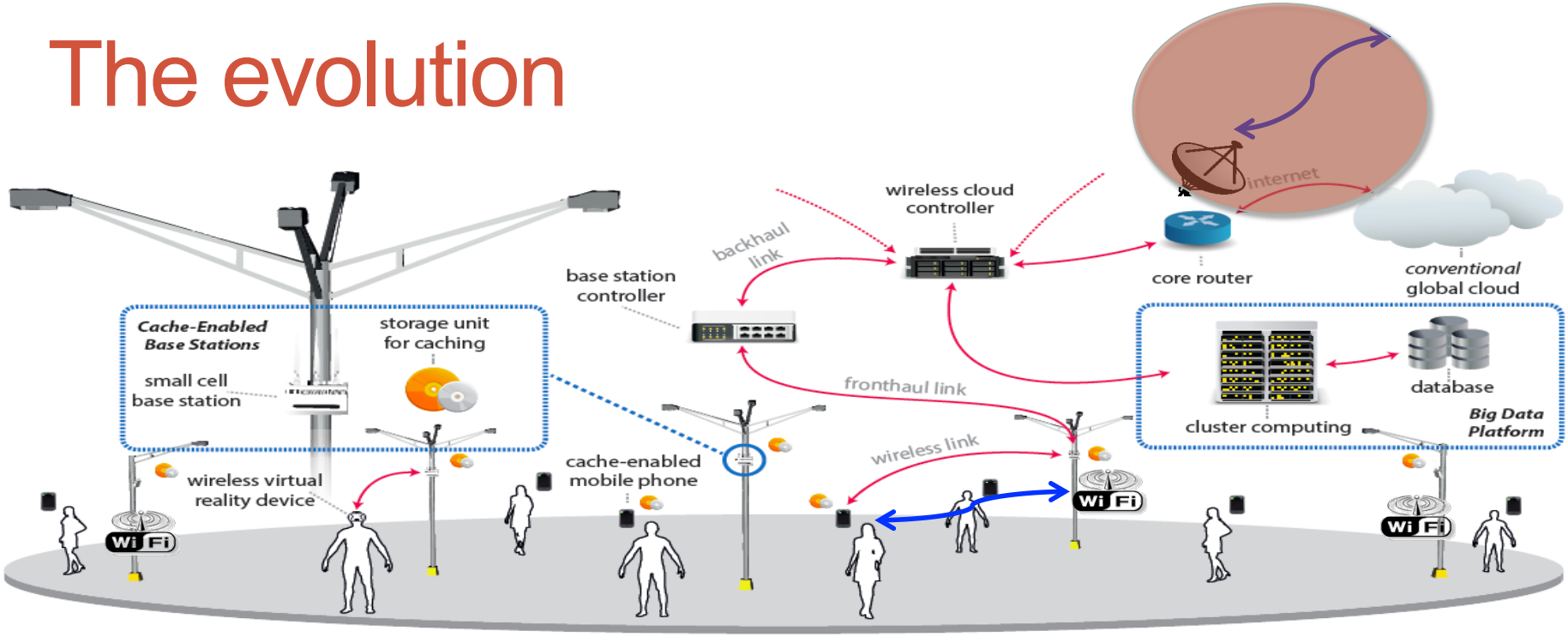
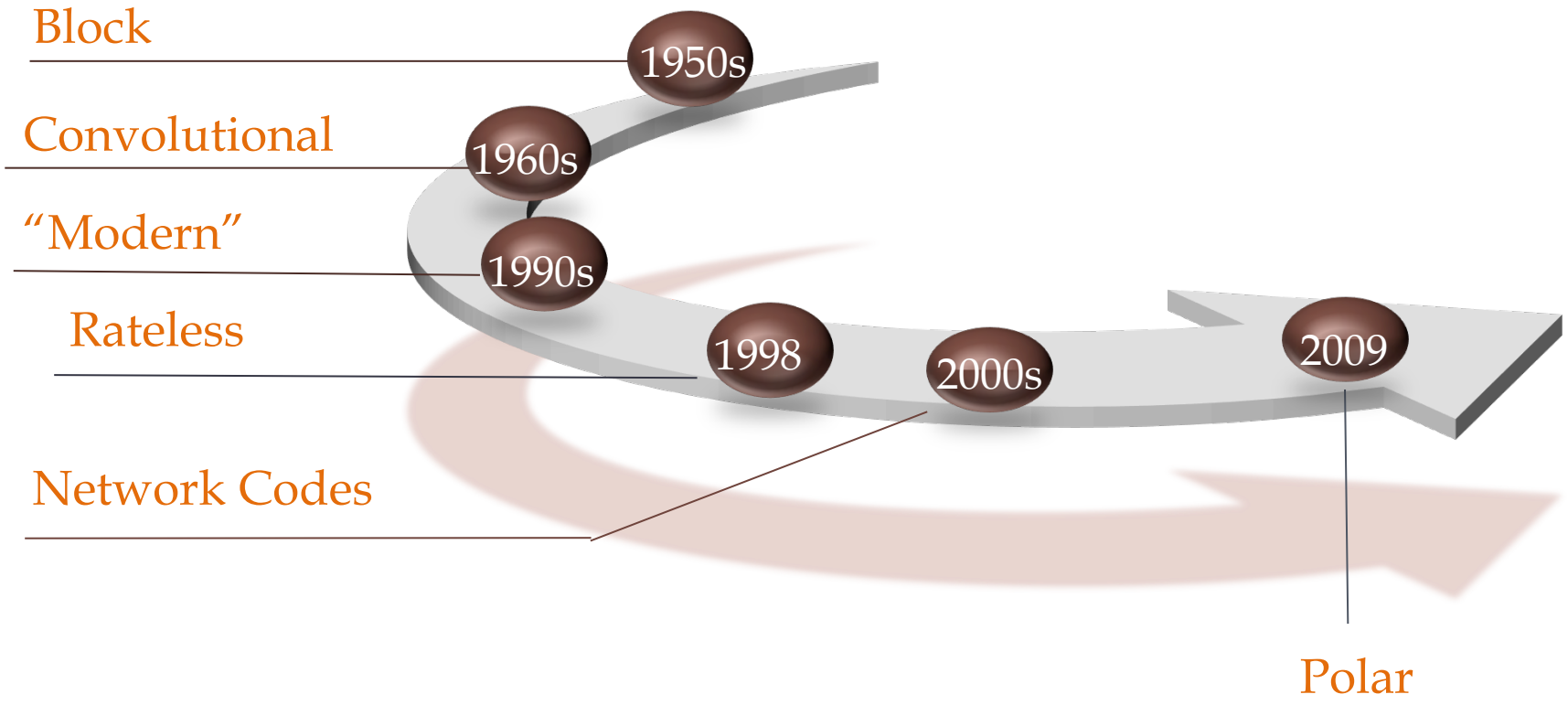
The evolution



Evolution of codes



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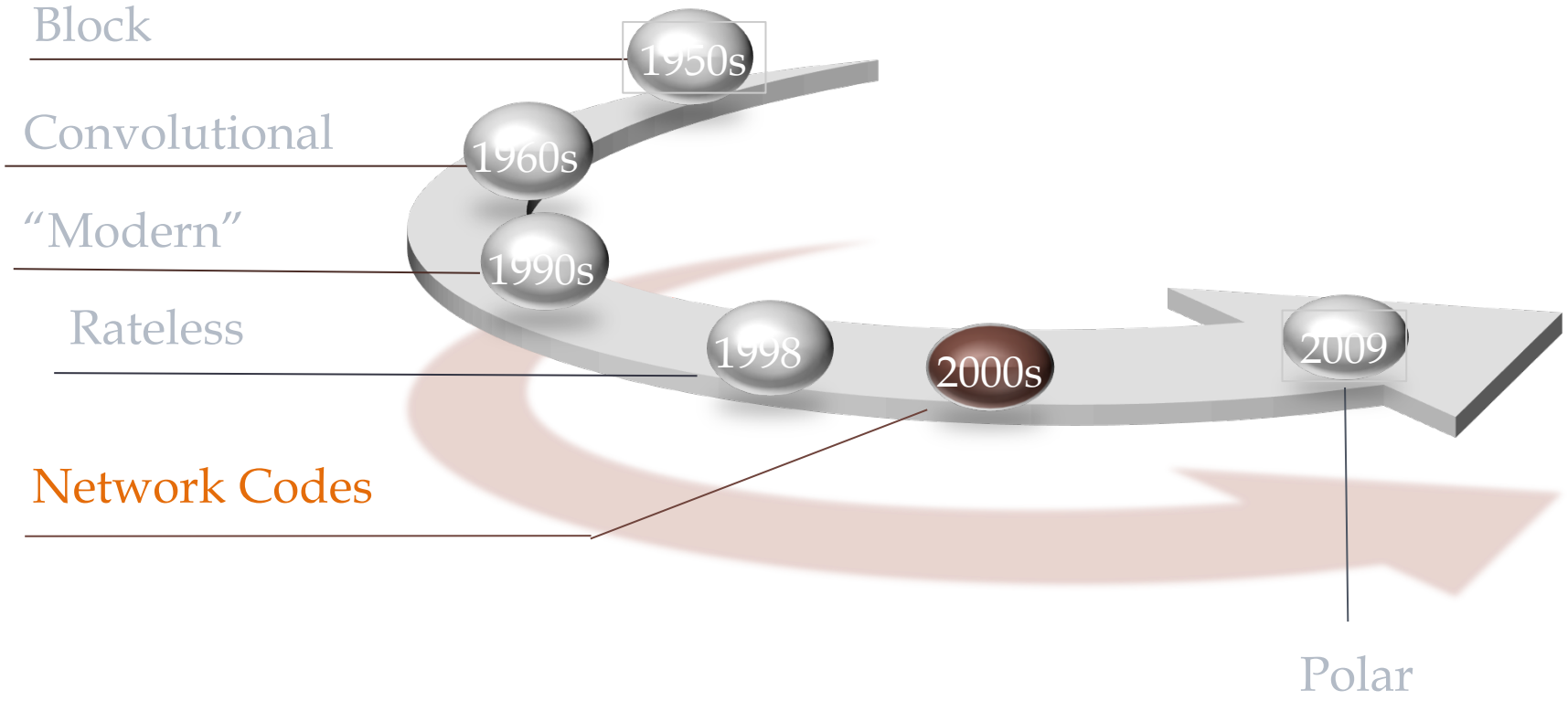
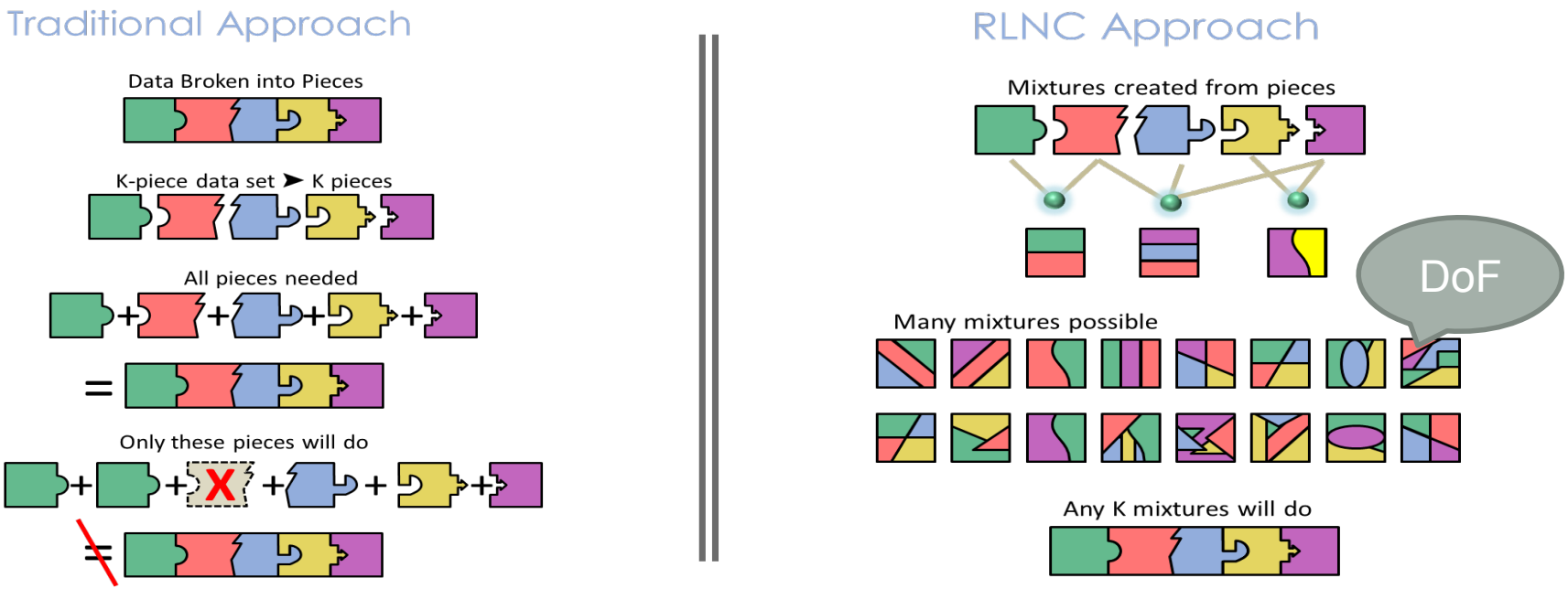


Random Linear Network Coding (RLNC)



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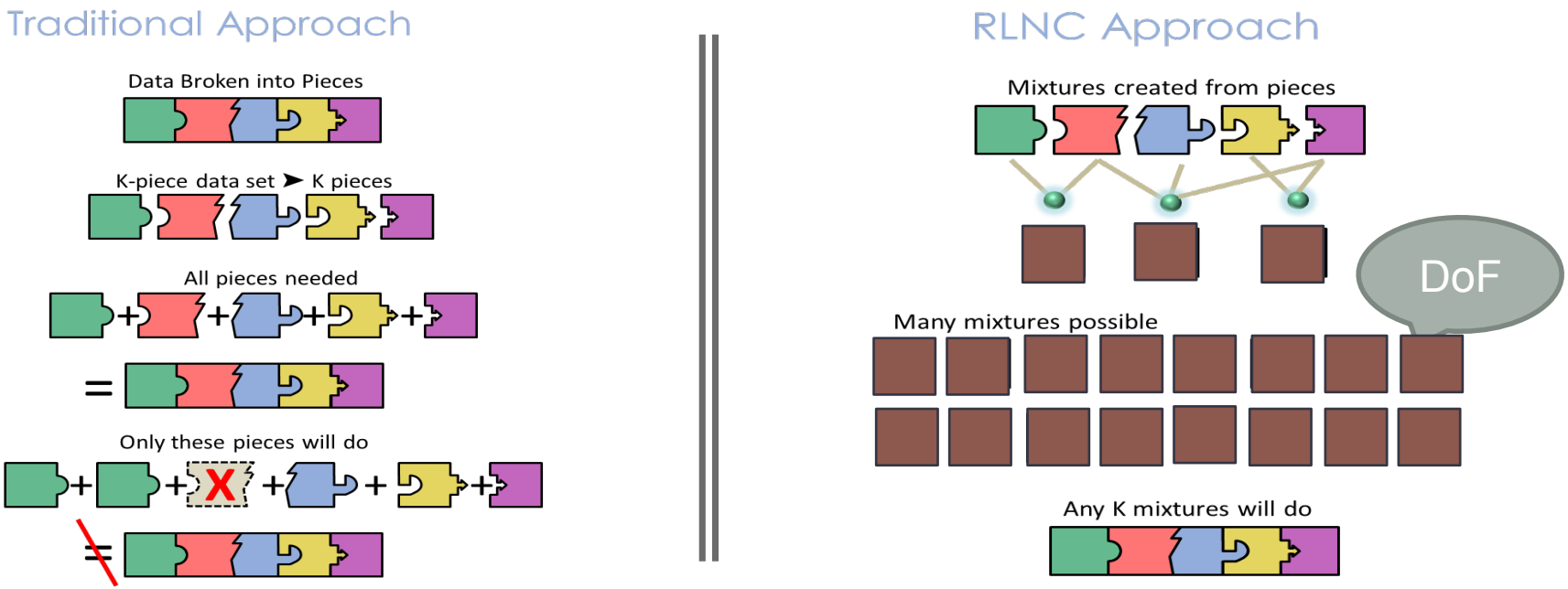
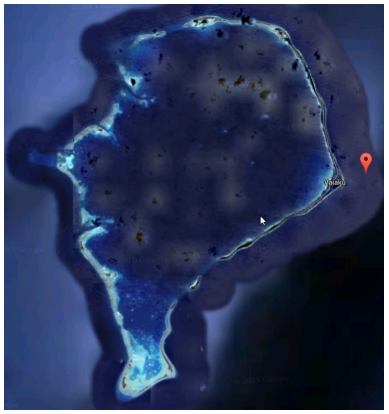
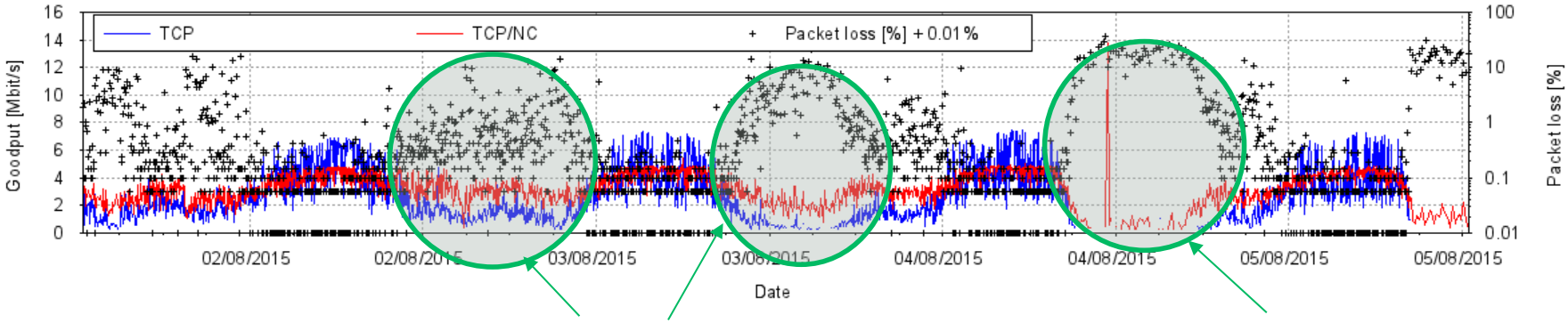


Funafuti, Tuvalu





TCP/NC maintains steady goodput with 1-10% packet loss

TCP/NC can complete some downloads even with >10% packet loss

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NYC

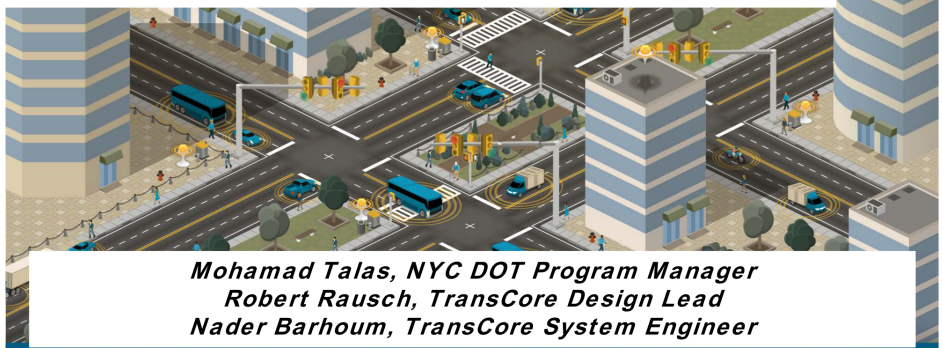
codeon

Steinwurf

U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology

CONNECTED VEHICLE PILOT
Deployment Program

New York City Pilot Acquisition and Installation Experiences

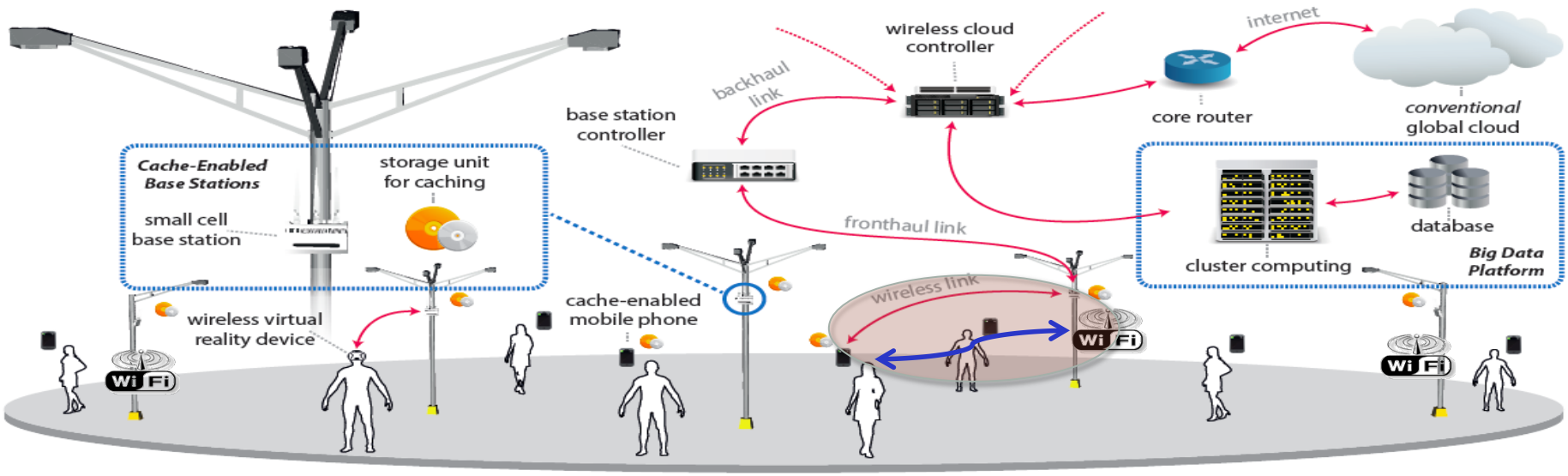


Mohamad Talas, NYC DOT Program Manager
Robert Rausch, TransCore Design Lead
Nader Barhoum, TransCore System Engineer

ITS Joint Program Office

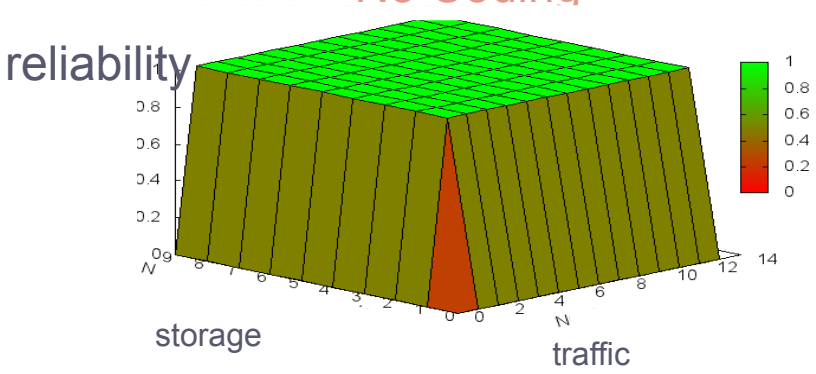
NEW YORK CITY DOT NYC Connected Vehicle Project
For Safer Transportation

The evolution

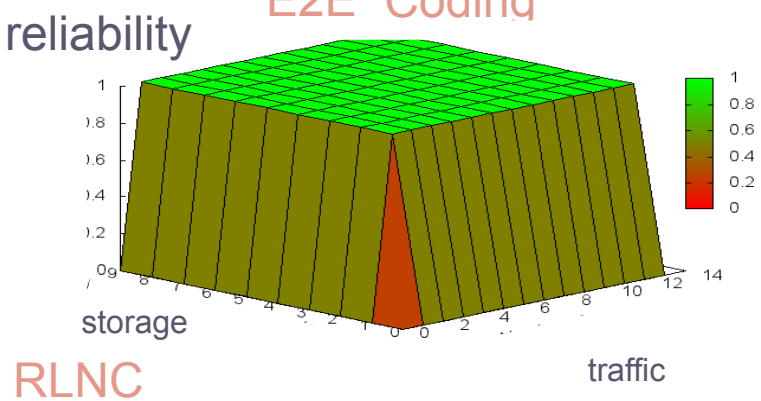


Managing data when nodes move

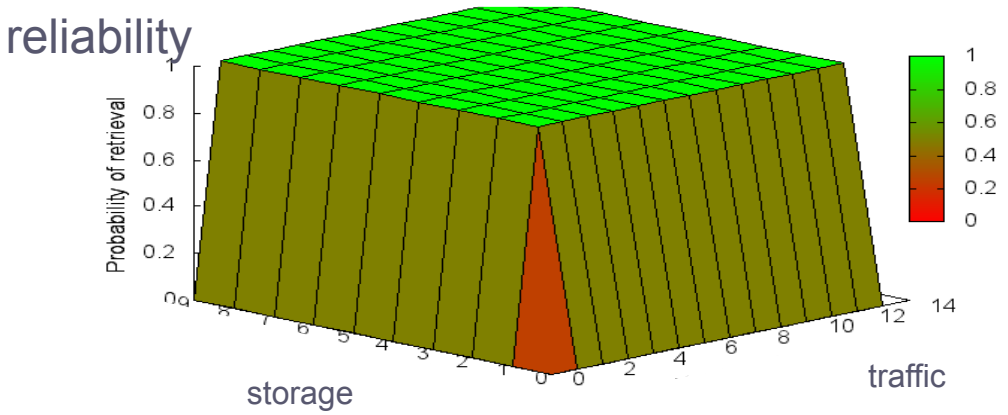
No Coding



E2E Coding



RLNC



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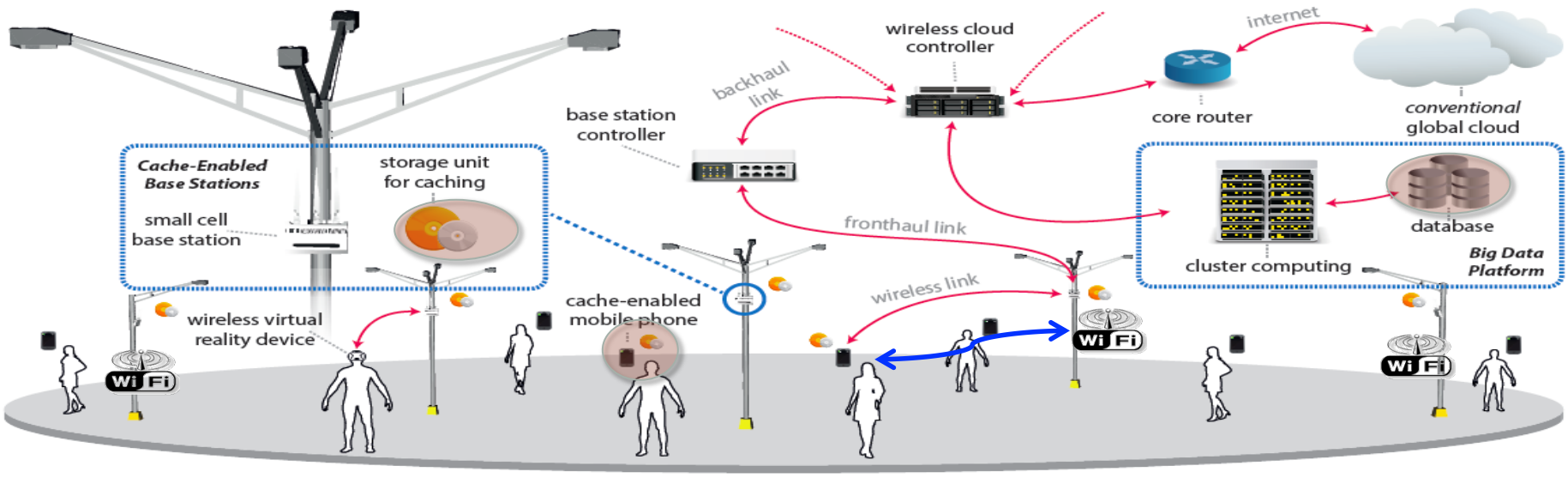
The evolution



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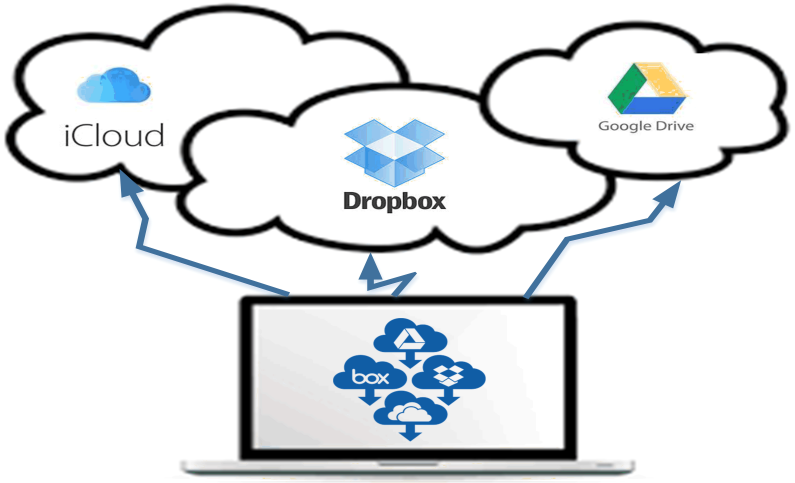
Trusted storage on untrusted nodes

- The coding hides data
- McEliece-style crypto-system

Chocolate Cloud



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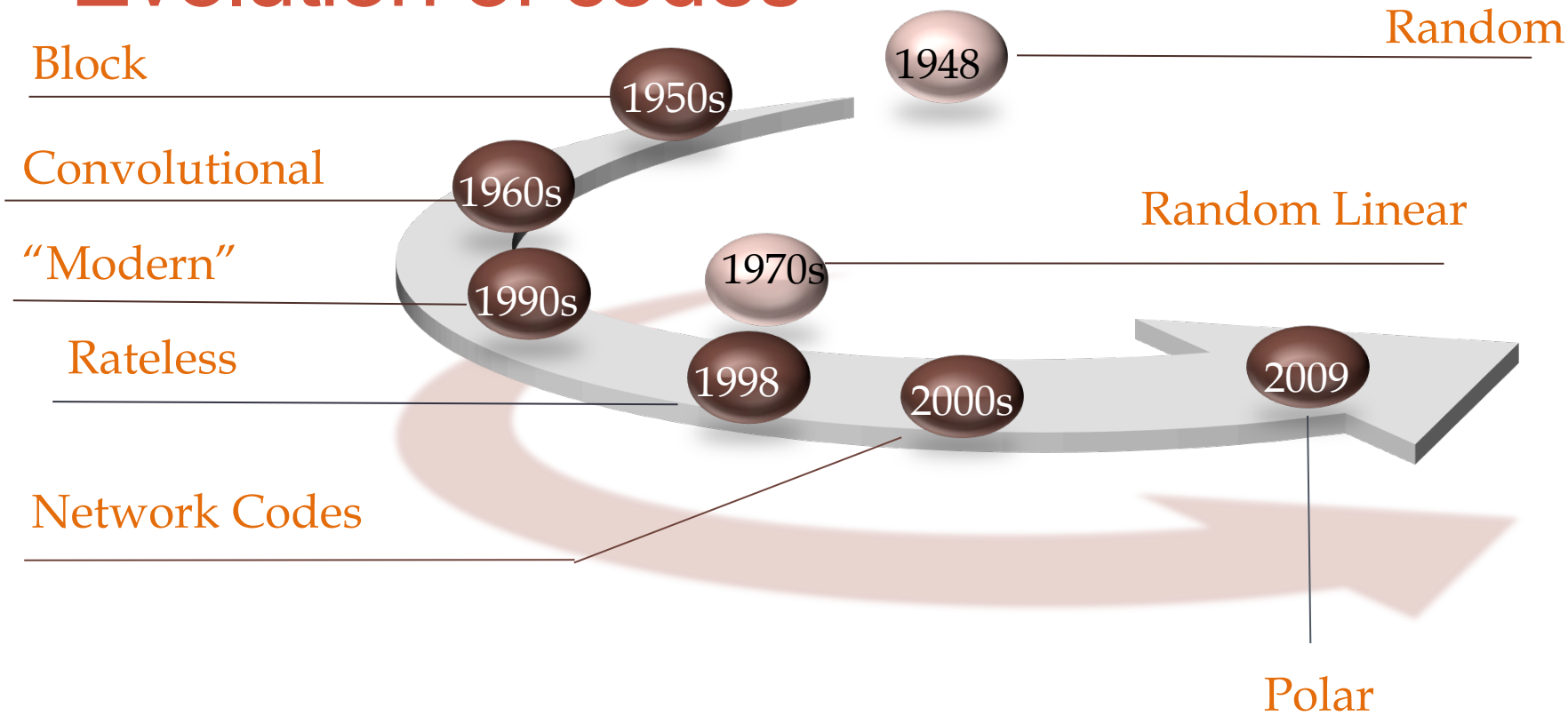
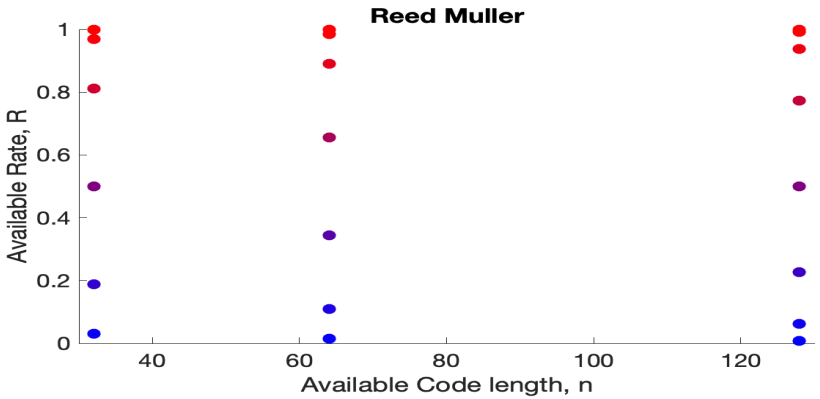
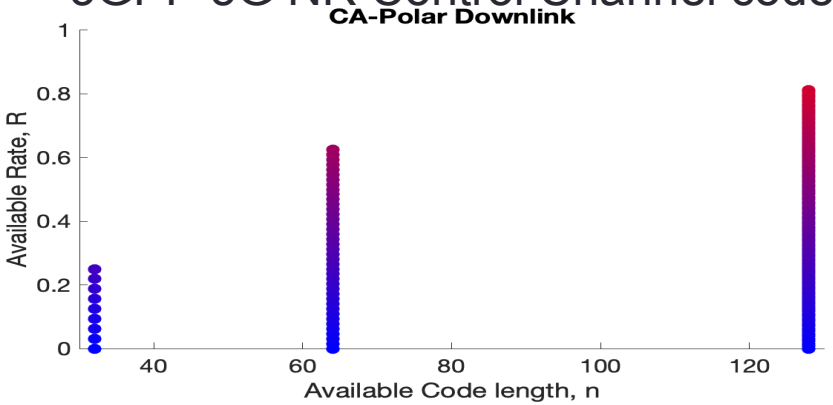


What codes do we have?

Classic codes

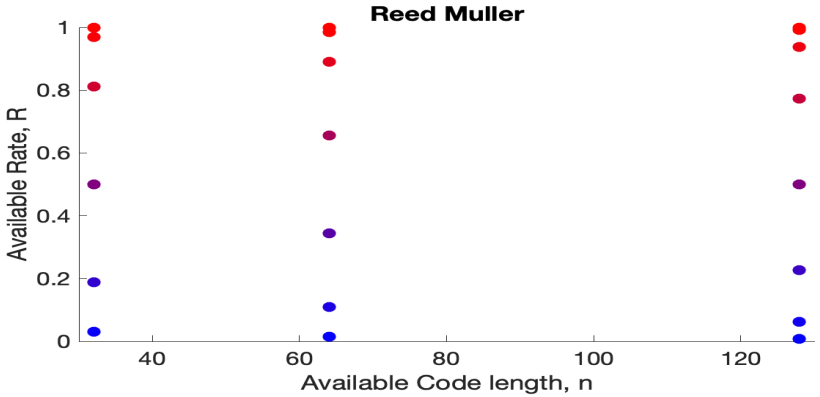


3GPP 5G NR Control Channel codes



What codes can we have?

Classic codes



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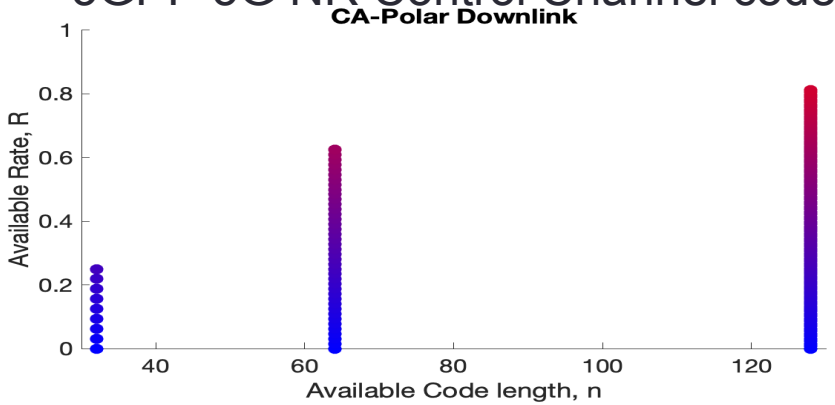

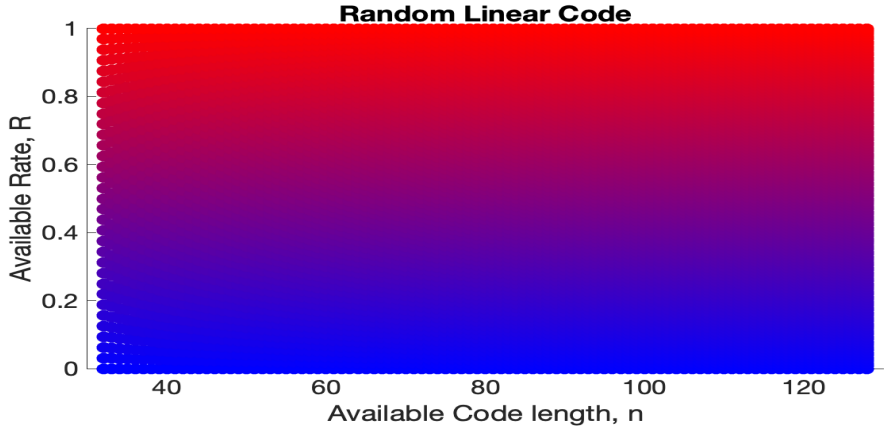

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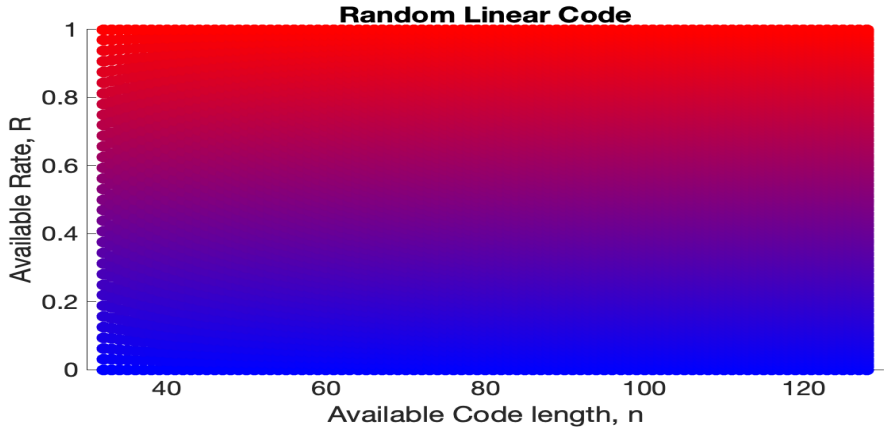

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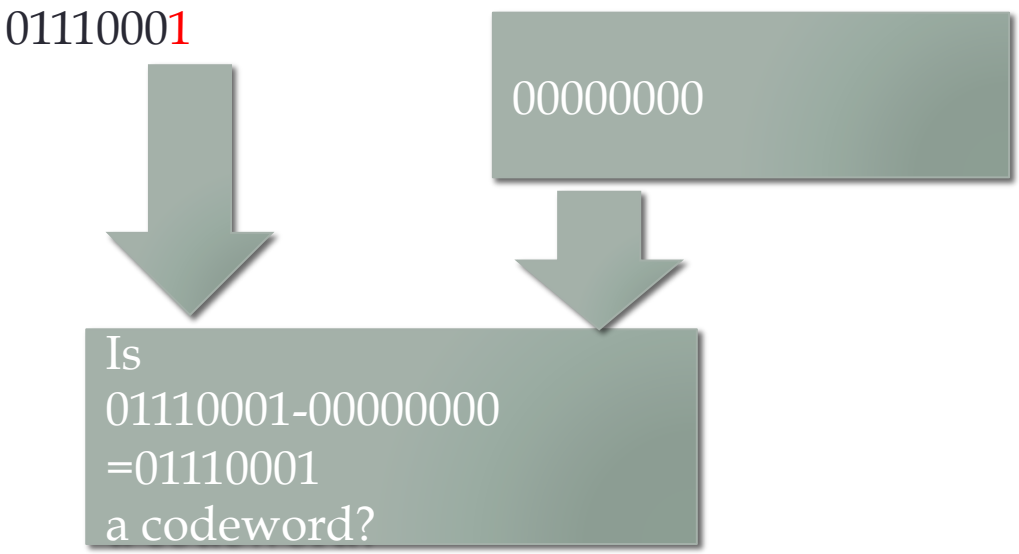
Guessing noise – example



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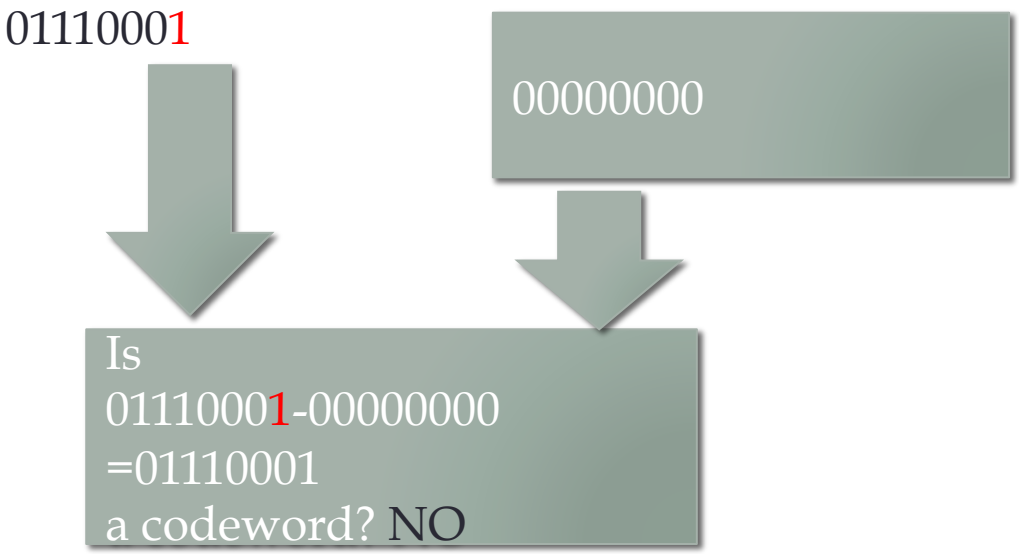

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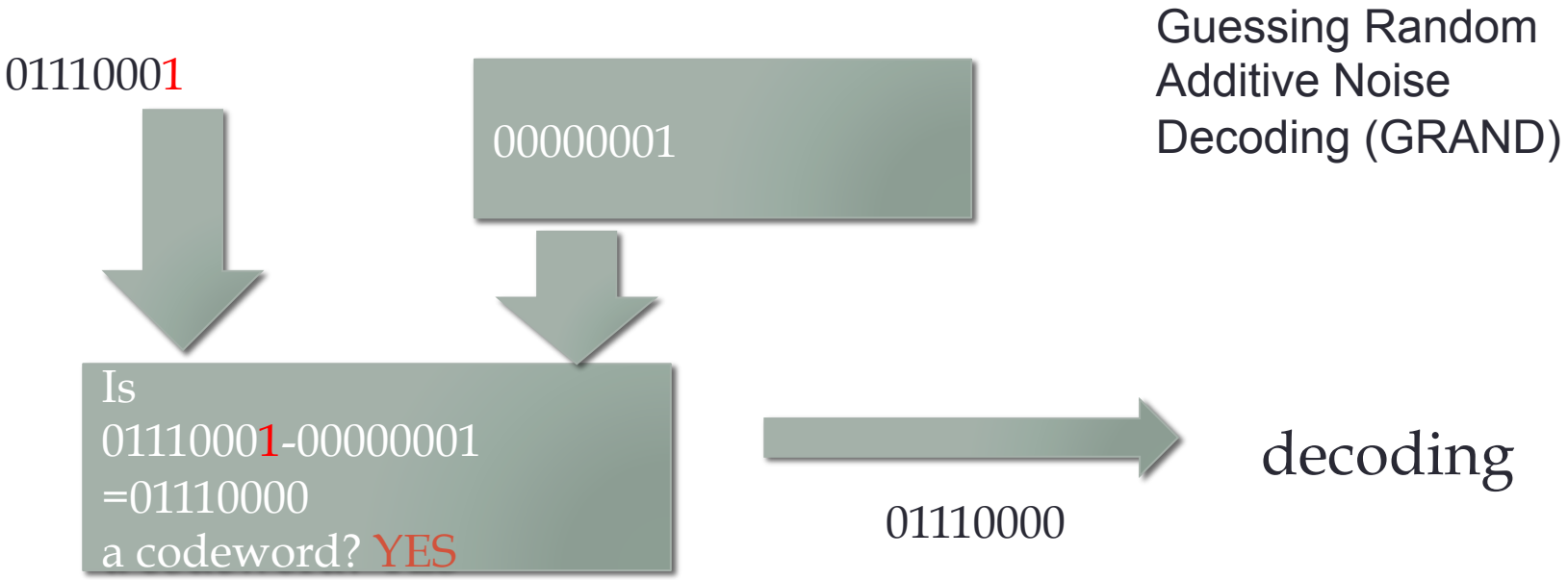
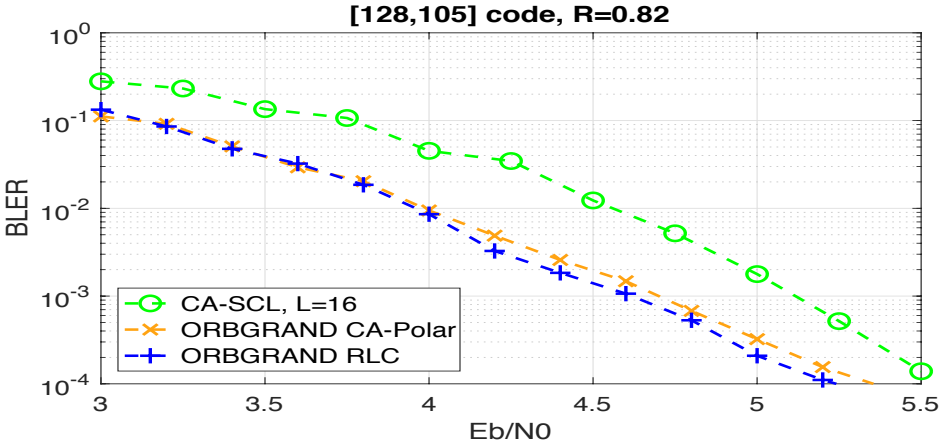
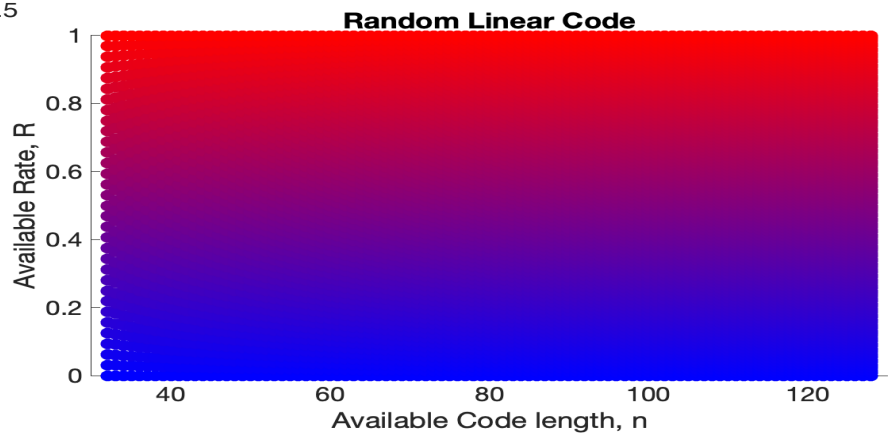


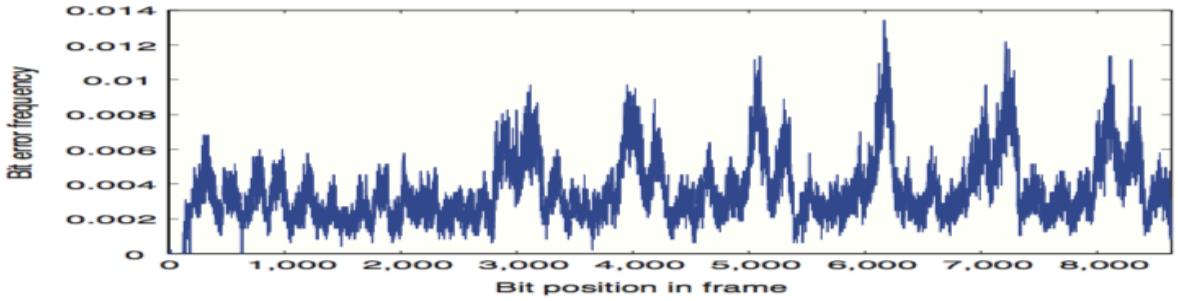
Guessing Random
Additive Noise
Decoding (GRAND)

What codes do we have?

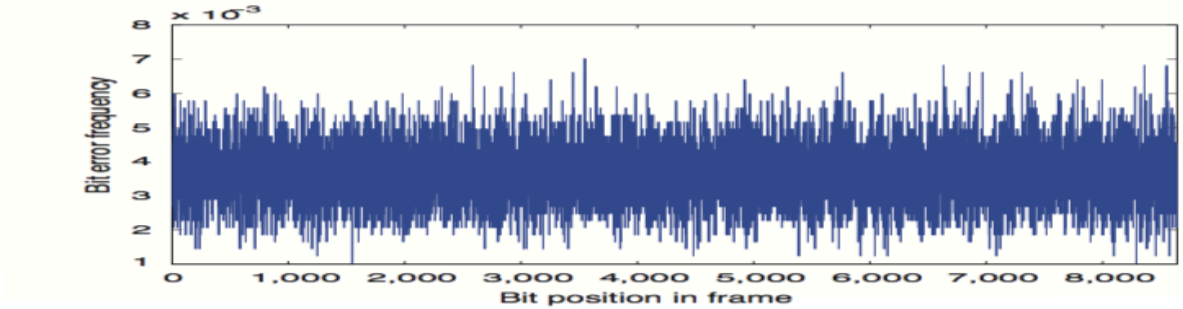




Interleaving



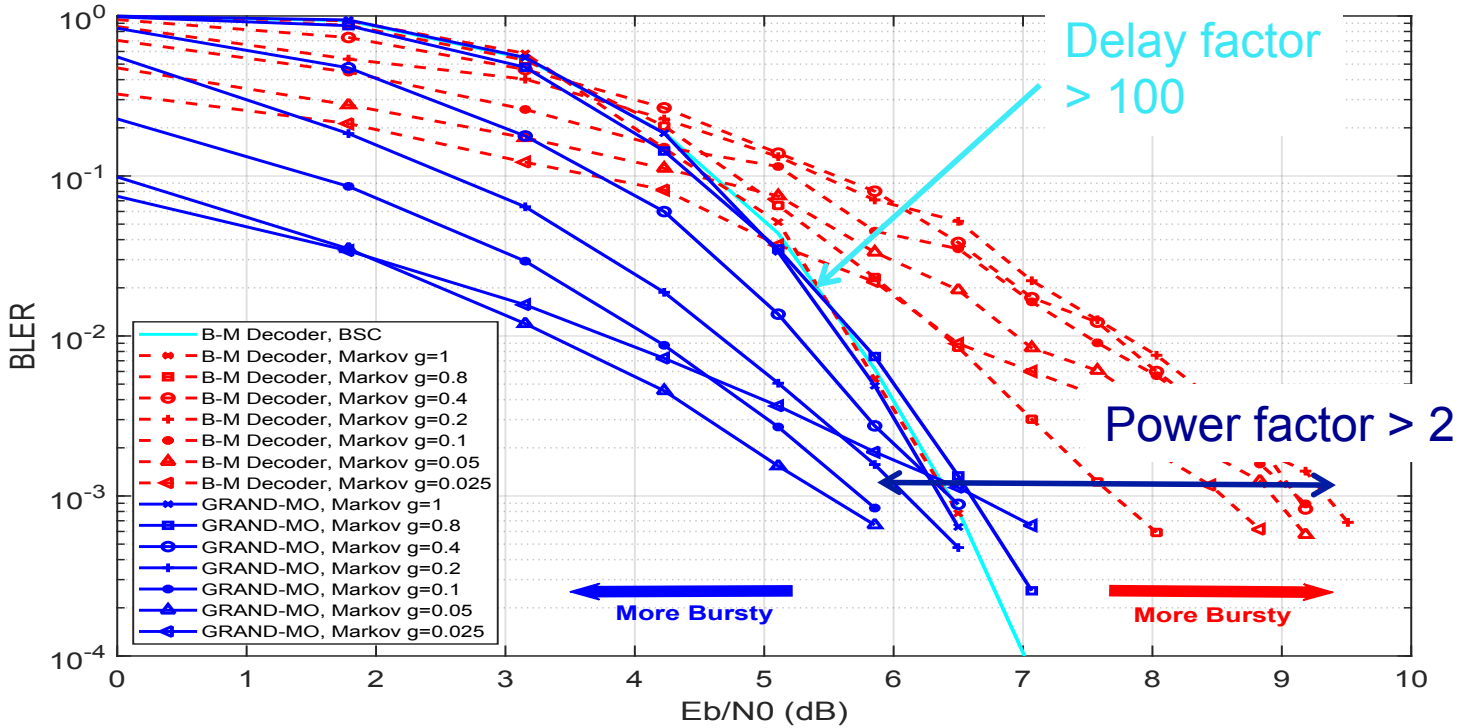
(a) Before interleaving



(b) After interleaving

X. Chen and D. J. Leith, IEEE Int. Conf. Comm. 2015

What about channel burstiness?



BCH[127,106] with the Berlekamp-Massey (B-M) and GRAND for bursts

An, Medard, Duffy, *preprint*, 20

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RANDOM CONSTRUCTIONS PROVIDE ROBUSTNESS

Médard, M. Is 5 just what comes after 4?. *Nat Electron* **3,** 2–4 (2020). https://doi.org/10.1038/s41928-019-0361-8