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“Multi-Base Station Coordination for Semi-Persistent Scheduling in Industrial 5G Wireless Time-Sensitive Networks”

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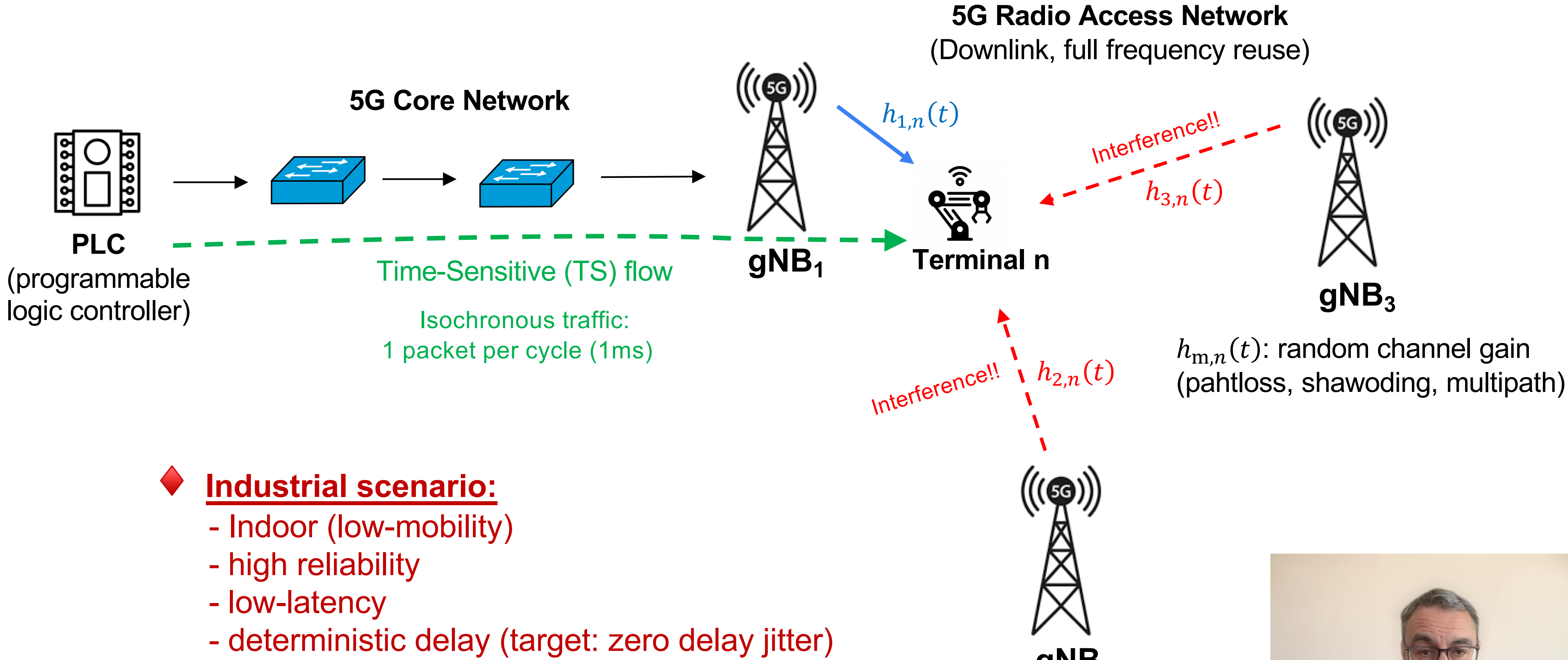
Problem Statement



Industrial scenario:

- Indoor (low-mobility)
- high reliability
- low-latency
- deterministic delay (target: zero delay jitter)

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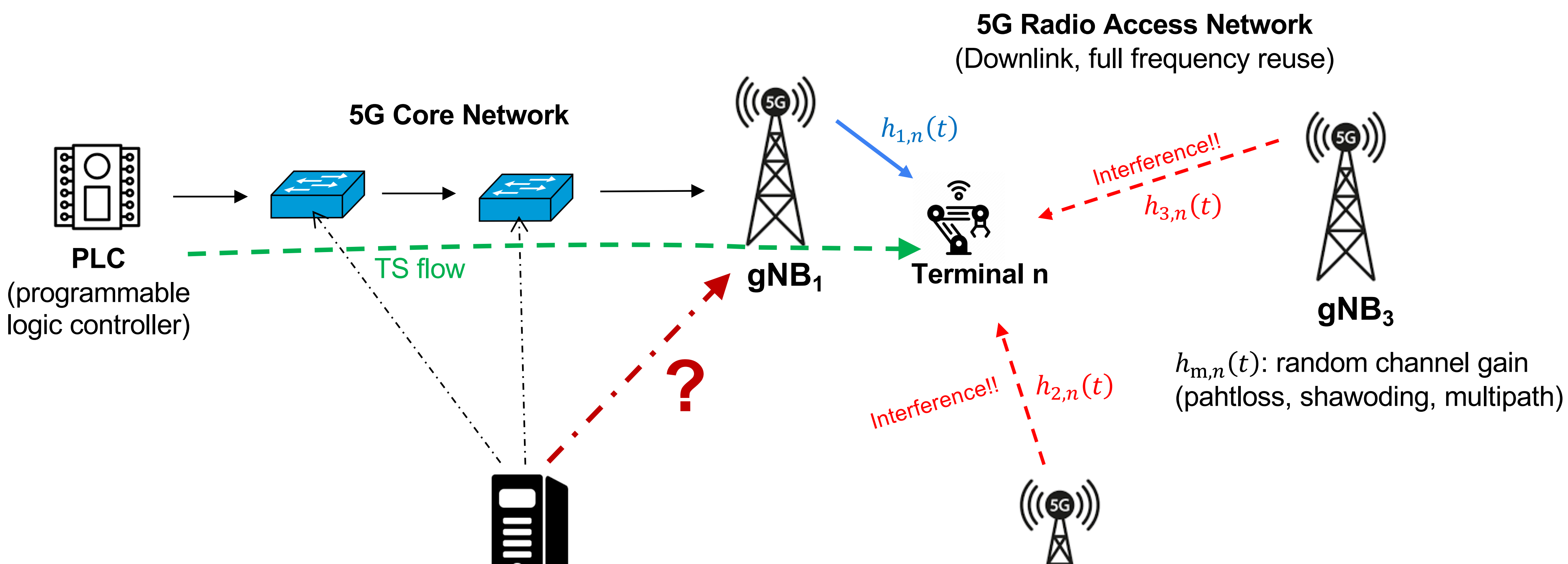
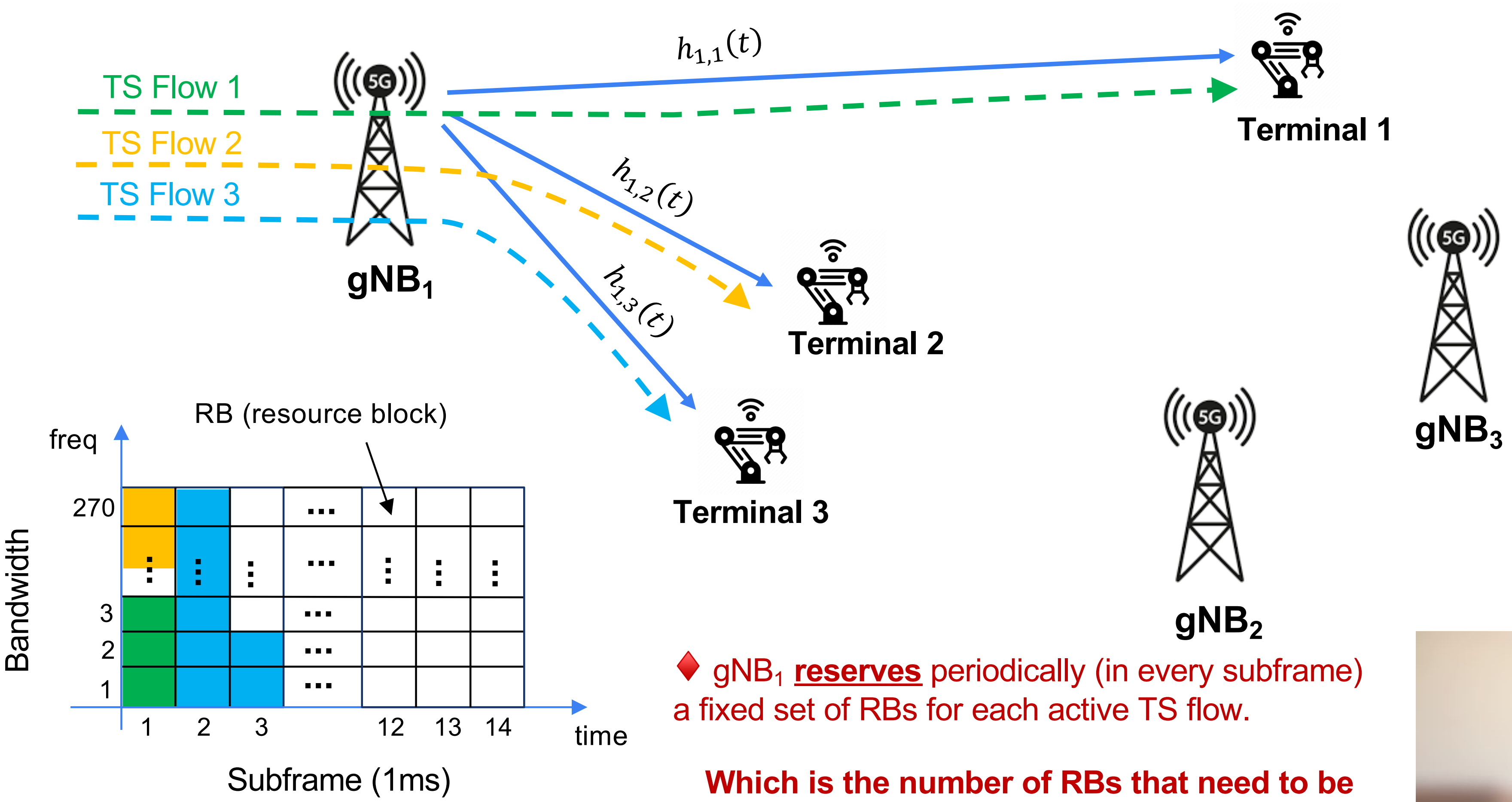


♦ TSN controller

- *Resources reservation to avoid packet delays in queues (802.1Qbv)*
- *Nodes synchronization* (802.1as)

Problem Statement



♦ gNB$_1$ **reserves** periodically (in every subframe) a fixed set of RBs for each active TS flow.

Which is the number of RBs that need to be reserved?

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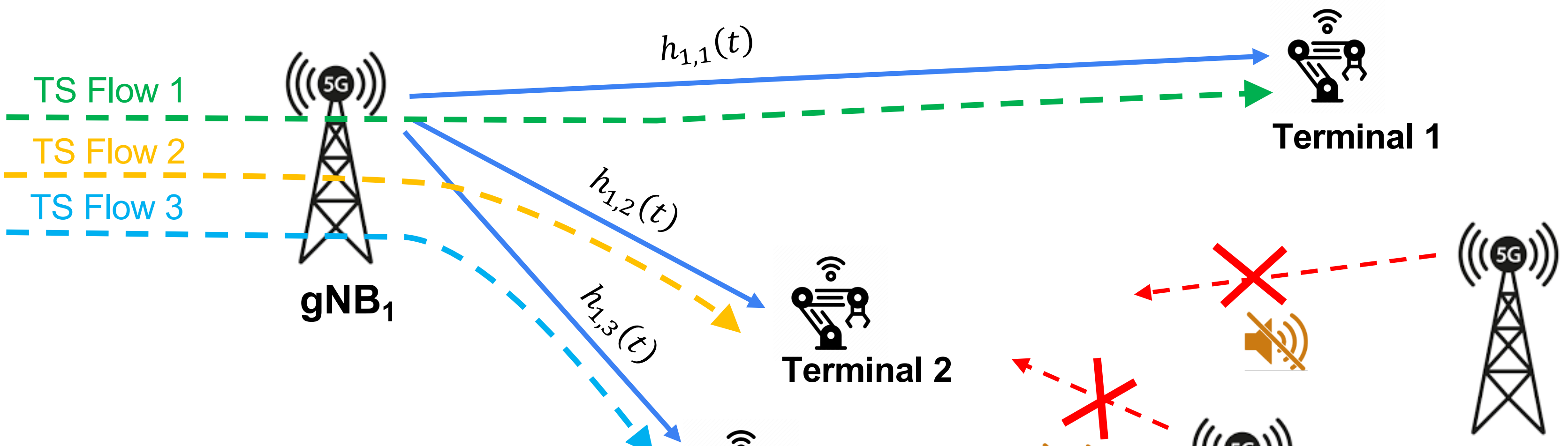
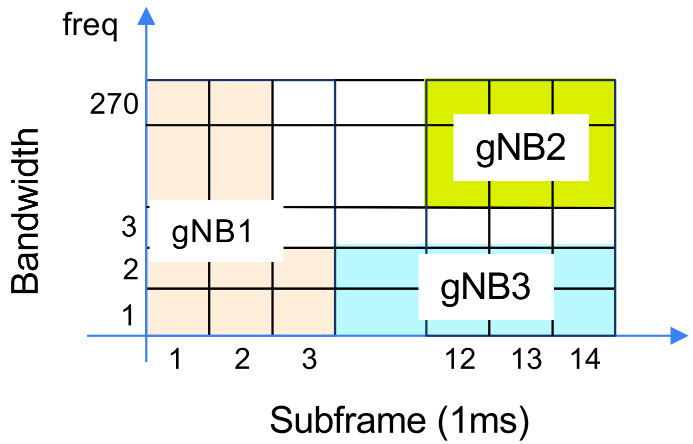
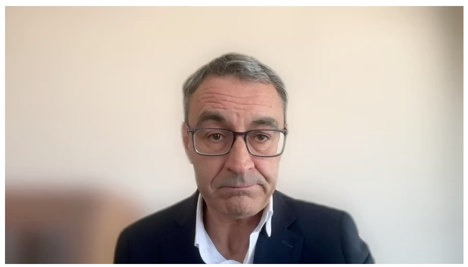




♦ Neighbour gNBs remain silent to avoid inteference ➔ **coordination**

How coordination is implemented?



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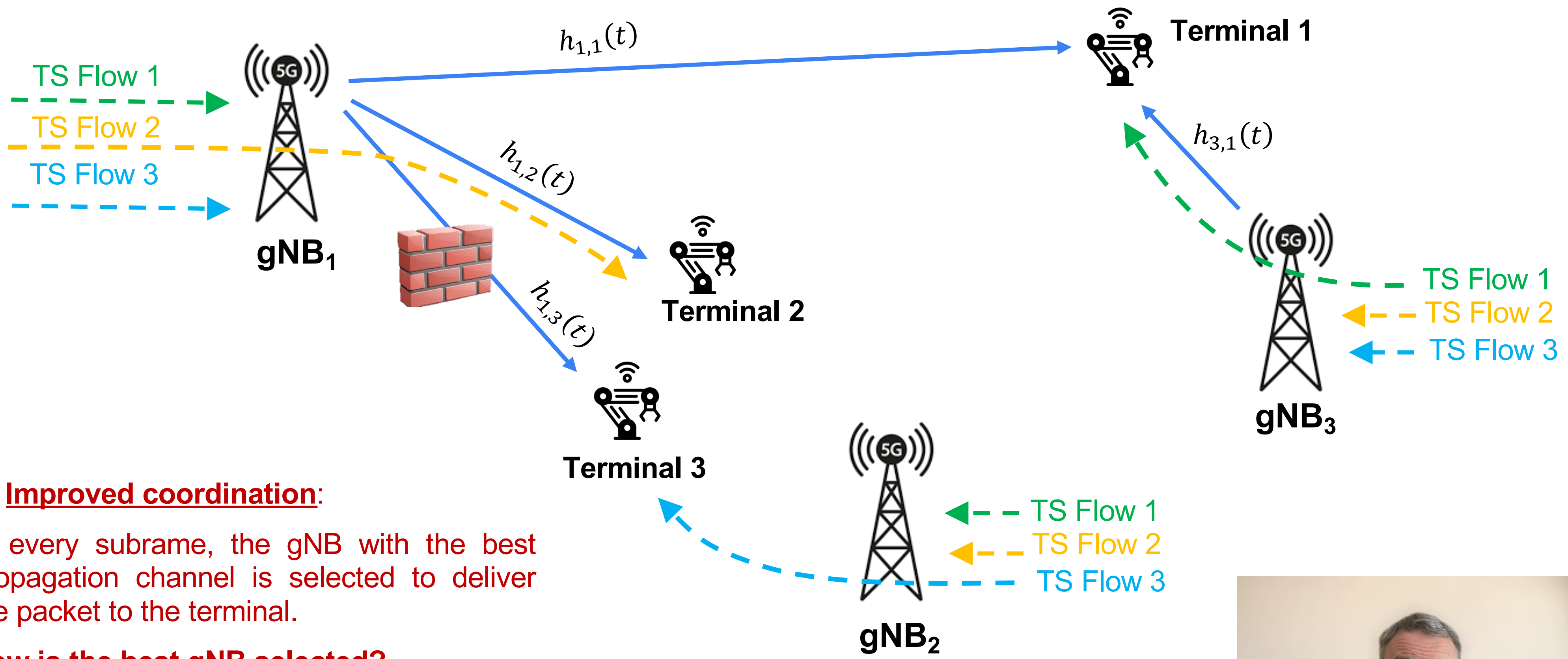

- **Improved coordination**:

In every subrame, the gNB with the best propagation channel is selected to deliver the packet to the terminal.

How is the best gNB selected?

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Coordinated radio frame design

1 **Channel estimation:** $$\hat{H}_{m,n}(k,j) = \sum_i \hat{h}_{m,n}(iT_s, jT_{coh}) e^{-j2\pi \frac{k}{N_{FFT}} i}$$

Subcarrier index

Time index
(multiples of coherence time)

2 **SNR calculation:** $$\text{SNR}_{m,n}(k,j) = \frac{E_s}{N_0} |\hat{H}_{m,n}(k,j)|^2$$

3 **Effective SNR calculation for MCS i = i_{max}:**

$$\text{SNR}^{\text{eff}}_{m,n}(j) = f_i^{-1}\left(\frac{1}{|\mathcal{K}|}\sum_{k\in\mathcal{K}} f_i\left(\text{SNR}_{m,n}(k,j)\right)\right)$$

RBIR (Received Bit Mutual Information Rate)
for the modulation of the ith MCS

Evaluated numerically!!

Table 5.1.3.1-3: MCS index table 3 for PDSCH

MCS Index I_{MCS}	**Modulation Order Q_m**	**Target code Rate R x [1024]**	**Spectral efficiency**
0	2	30	0.0586
1	2	40	0.0781
2	2	50	0.0977
3	2	64	0.1250
4	2	78	0.1523
5	2	99	0.1934
6	2	120	0.2344
7	2	157	0.3066
8	2	193	0.3770
9	2	251	0.4902
10	2	308	0.6016
11	2	379	0.7402
12	2	449	0.8770
13	2	526	1.0273
14	2	602	1.1758
15	4	340	1.3281
16	4	378	1.4766
17	4	434	1.6953
18	4	490	1.9141
19	4	553	2.1602
20	4	616	2.4063
21	6	438	2.5664
22	6	466	2.7305
23	6	517	3.0293
24	6	567	3.3223
25	6	616	3.6094
26	6	666	3.9023
27	6	719	4.2129
28	6	772	4.5234
29	2	reserved	
30	4	reserved	
31	6	reserved	

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Coordinated radio frame design

4 **gNB selection:** gNB that maximizes the effective SNR of terminal n at time j

$$\mathrm{SNR}_n^{\mathrm{eff}}(j) = \max_m \mathrm{SNR}_{m,n}^{\mathrm{eff}}(j) \Longrightarrow \boxed{m_n(j) = \arg\max_m \mathrm{SNR}_{m,n}^{\mathrm{eff}}(j)}$$

5 **Modulation and Coding Schem (MCS) selection:**

$\mathrm{SNR}_n^{\mathrm{eff}}(j) > \mathrm{SNR}_i$

Minimum SNR required by MCS i to attain the target BLER

yes → Select the current i $\Longrightarrow \boxed{MCS_n(j) = i}$

no → i=0?

- yes → Go back to step (3) and try $\mathrm{i} \longrightarrow \mathrm{i} - 1$
- no → *No coverage!!*

Coordinated radio frame design

6 **Compute offline the selected MCS during J channel realizations of the channel:**

$$\mathbf{MCS}_n = [\mathrm{MCS}_n(1), \ldots, \mathrm{MCS}_n(J)]$$

7 **Compute the histogram of** $\mathbf{MCS}_n$ **:**

$$p_i = \frac{1}{J}\sum_j \mathbb{I}_{\mathrm{MCS}_n(j)=i}$$

Prob of requiring more than the reserved RBs

8 **Determine the number of RBs reserved for the nth flow:**

$$N^*_{RB}(n) = \lceil T_{BS}/(12R_{i^*})\rceil$$ with i^* the solution to $$\sum_{i=0}^{i^*-1} p_i \leq p_{loss}$$

Transport Block

Rate (bpcu) of MCS i^*

9 **Determine the total number of RBs reserved for TS traffic:**

$$\boxed{N_{RB} = \sum_{n=1}^{N} N^*_{RB}(n)}$$

Coordinated radio frame design

(6) **Compute offline the selected MCS during J channel realizations of the channel:** $\mathbf{MCS}_n = [\mathbf{MCS}_n(1), \ldots, \mathbf{MCS}_n(J)]$

(7) **Compute the histogram of** $\mathbf{MCS}_n$**:** $p_i = \frac{1}{J}\sum_j \mathbb{I}_{\mathrm{MCS}_n(j)=i}$

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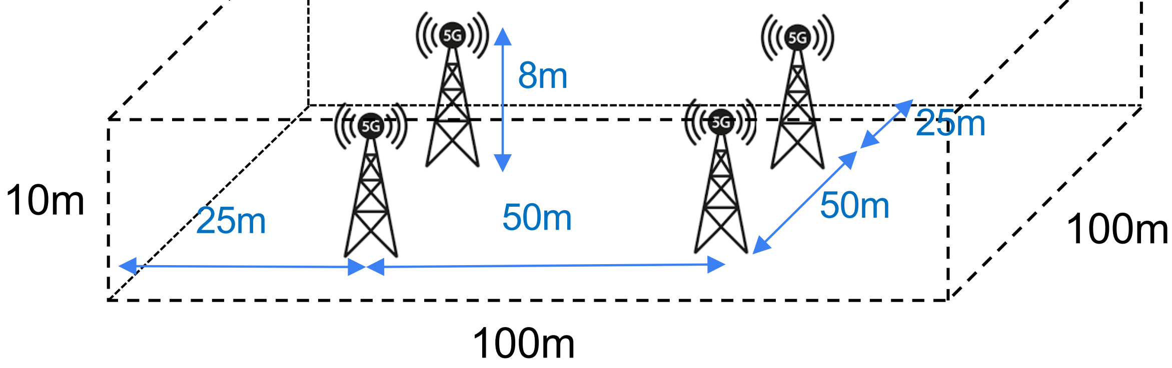
Simulated scenario

Factory Hall



Indoor factory channel model (Inf-SH) [3GPP TR 38.901]

PROPAGATION CHANNEL PARAMETERS

Parameter	Value
Frequency (f)	3.5 GHz
Multipath model	TDL-B (Rayleigh taps)
Delay spread	57 ns
Shadowing (std)	5.9 dB (log-normal)
Pathloss model	$32.4 + 23\log_{10}(d) + 20\log_{10}(f)$
User terminal height	1.5 m

5G NR CONFIGURATION

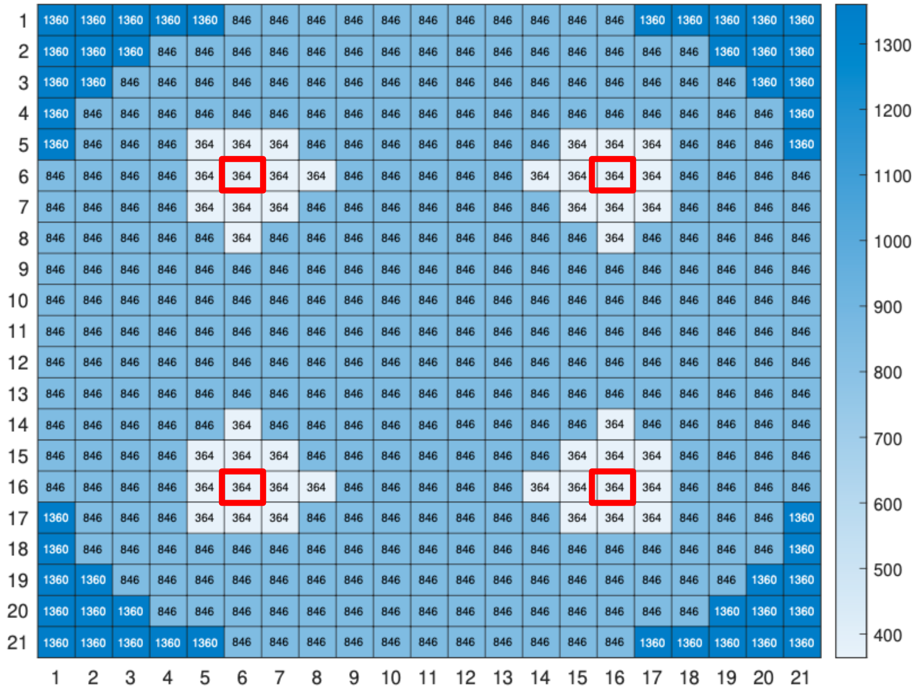
Parameter	Value
Transmitted E_s/N_0 (dB)	87.7 - 130.9 dB
Bandwidth	50 MHz
Subframe duration	1 ms
Subcarrier spacing (Δf)	15 kHz ($\mu = 0$)
Symbol duration including CP (T)	71.4 μs
Transport block size (TBS)	3780 bits
Block Error Rate (BLER)	$5 \cdot 10^{-4}$
Number of RBs (NRB) per symbol (K)	270
Number of RBs (NRB) per subframe ($N_{RB,\max}$)	3600
Number of RBs (NRB) for signaling (S_{RB})	180 (approx. 5%)

5G configuration [3GPP TS 38.214, TS 38.212]

Simulation results

$N^*_{RB}(n)$: Number of reserved RBs depending on the position of terninal n

100m



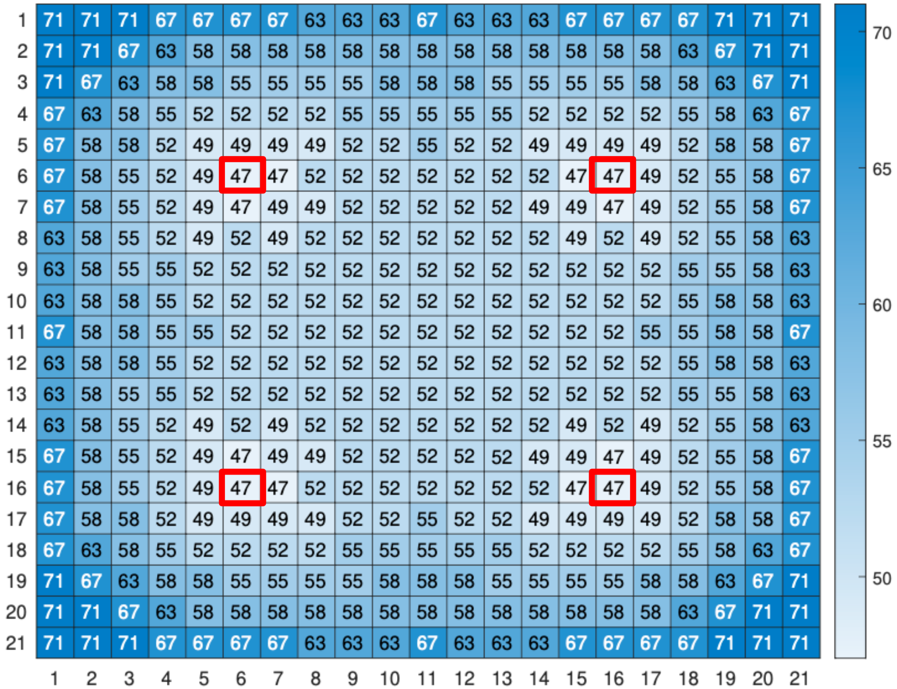
100m

gNBs position

Mimimum transmitted power to guarantee coverage over all the map

Simulation results

$N^*_{RB}(n)$: Number of reserved RBs depending on the position of terninal n



100m

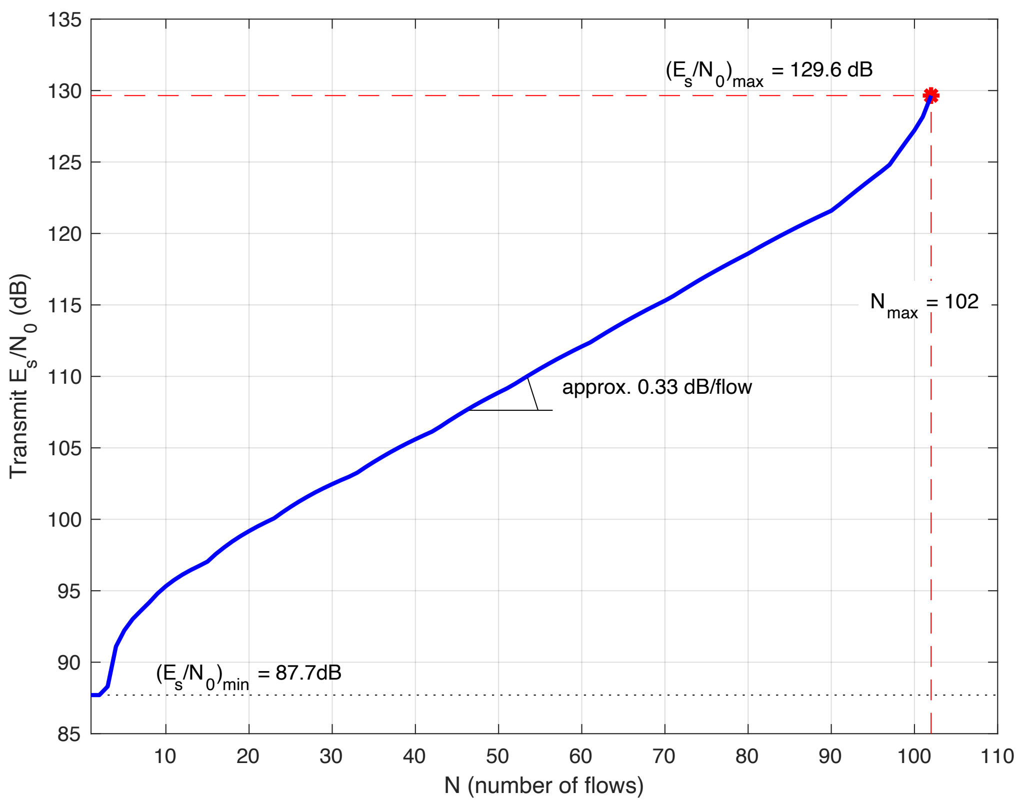
100m

gNBs position

Increased transmitted power to increase throughput and reduce number of RBs

Simulation results

(scaled) Transmit Power



Number of TS flows

N randomly deployed terminal
(1 flow per terminal)

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Main conclusions

- Window **reservation mechanism** for 5G compatible with IEEE 802.1Qbv
- **Coordination** is essential to cope with interference and exploit macro-diversity in industrial multi-gNB scenarios.
- **Transmitted power** can be used to increase the number of time-sensitive flows handled by the 5G radio access network.