Chair Risk and Resilience of Complex Systems Annual Scientific Seminar
Talk 6 (Industrial partner Orange)

Resilient railway 5G network : service availability and reliability assessment

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28 Sep 2023

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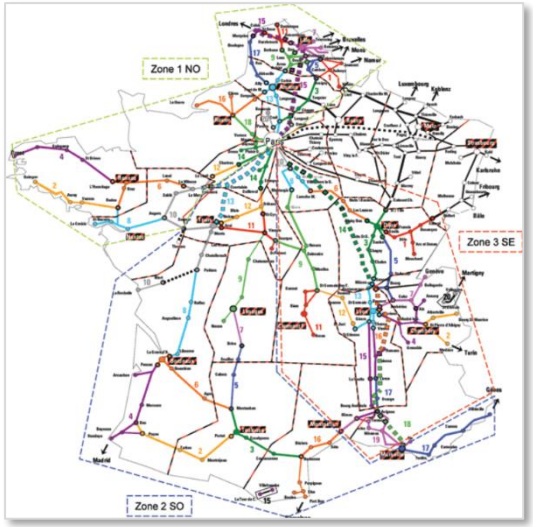
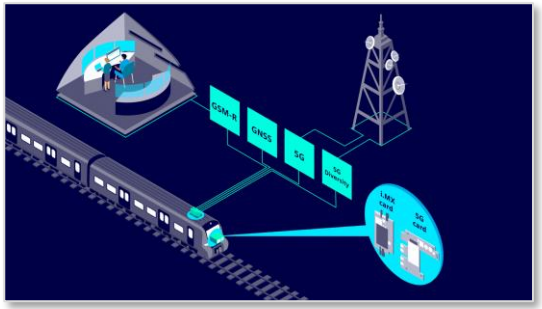
Built for Railway, GSM-R networks are the most reliable mobile networks currently in existence.





GSM-R networks will start to be life-expired by 2030.

Future Railway Mobile Communication System (FRMCS): to usher in 5G.

Rémi Bévot, Olivier Labourdette(2010, January). GSM-R in France.[Online available] https://www.globalrailwayreview.com/article/4247/gsm-r-in-france/.
UIC (2020, December). FRMCS and 5G for rail: challenges, achievements and opportunities. Publication of UIC rail system department. [Online available] https://uic.org/IMG/pdf/brochure_frmcs_v2_web.pdf.

From RST in GSM-R to various use cases expected in 5G networks

Use case	Characteristic parameters				Influence parameters						
	Communication service availability: target value (note 1)	Communication service reliability: mean time between failures	End-to-end latency: maximum (note 2)	Service bit rate: user experienced data rate	Communication pattern	Message size	Transfer interval: target value	Survival time	UE speed	# of UEs	Service area (note 3)
1: Control of automated train (note 4)	99,999 %	below 1 year but >>1 month	<100 ms	≥200 kbit/s	periodic deterministic	≤200 byte	100 ms	~500 ms	≤160 km/h	<25	50 km x 200 m
2: CCTV communication service for surveillance cameras (note 4)	>99,99 %	~1 week	<500 ms	≥2 Mbit/s	aperiodic deterministic			~500 ms	≤160 km/h	<25	50 km x 200 m
3: Emergency voice call (note 4)	>99,99 %	~1 day	<200 ms	≥200 kbit/s	aperiodic deterministic			~2 s	≤160 km/h	<25	50 km x 200 m
4: Train coupling	>99,9999 %	~1 year	<100 ms	1 Gbit/s	mixed traffic			~500 ms	– (note 5)	2	3 m x 1 m
5: CCTV offload in train stations				≥1 Gbit/s	non-deterministic				~0 km/h	≥1	train station

Table of KPIs of communication service performance requirements for rail-bound mass transit.

Availability : Up to 99.9999%
Reliability : More than 1 year

Scenarios:

- Automated train
- Train coupling
- Video/voice communication

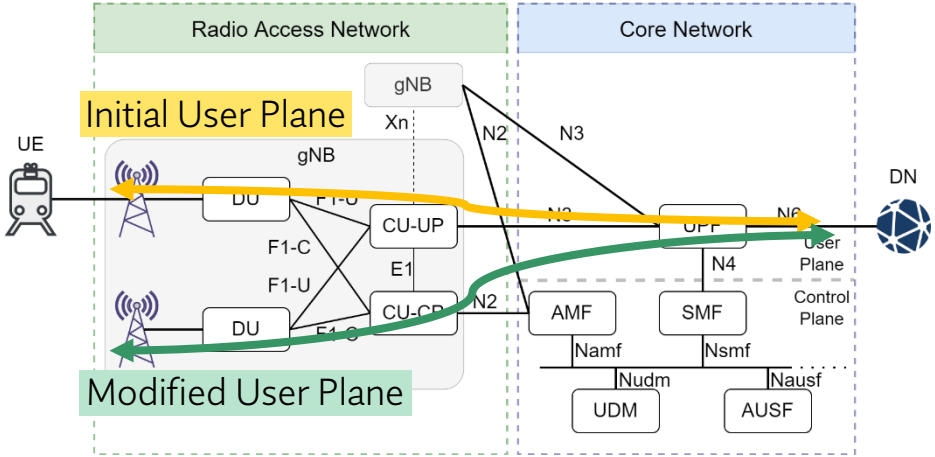
Environment and context:

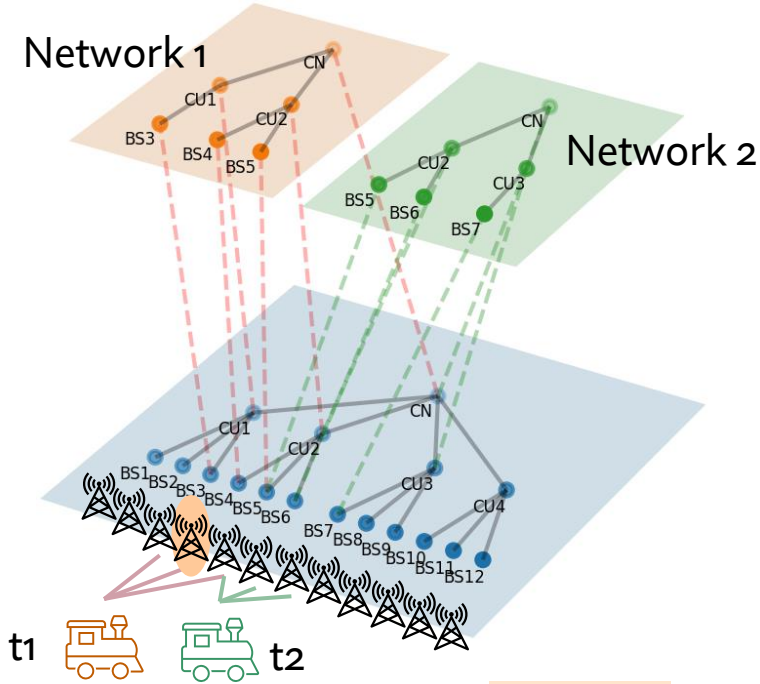
- Speed:
  160 km/h (mass transit) – 500 km/h (high-speed)
- Surroundings:
  Tunnel & mountain environment
- End users:
  Train(s), passengers, control center
- Traffic pattern:
  Nondeterministic

3GPP (2022, May). LTE; 5G; Mobile communication system for railways (3GPP TS 22.289 version 17.0.0 Release 17)

5G for railway communication service mainly relies on the **User Plane**.

But the User Plane is no longer static.



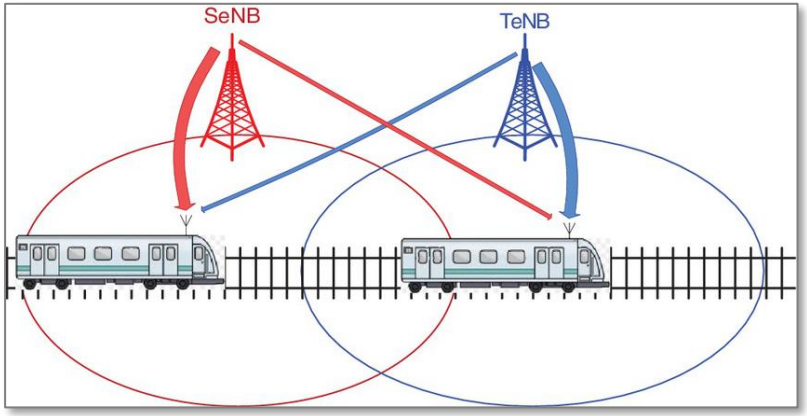


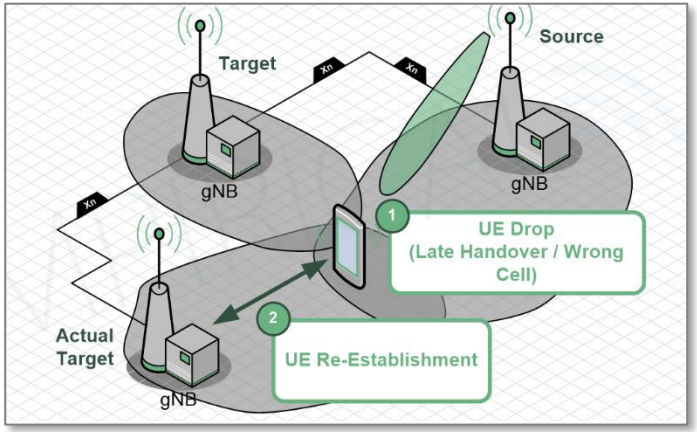
Train is connected to sub network 1 at t1

Train is connected to sub network 2 at t2

1st challenge: resilient session Handover (HO)

- Modeling of Control Plane HO process
- Interaction with User Plane





2nd challenge: connection Re-establishment (RE)

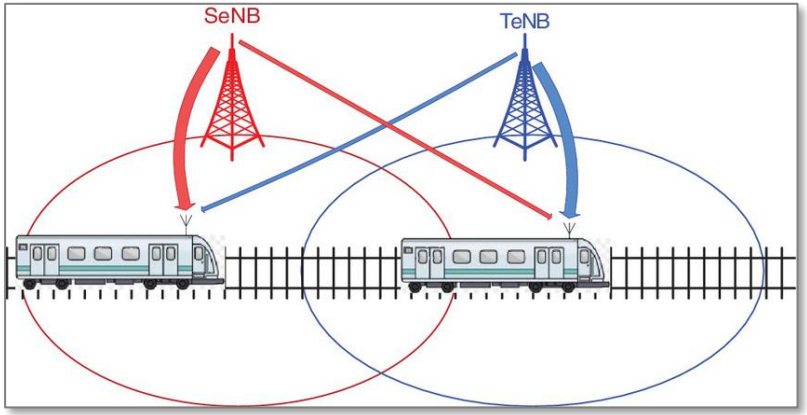
- Modeling of Control Plane RE process
- Simulation on service failure and recovery

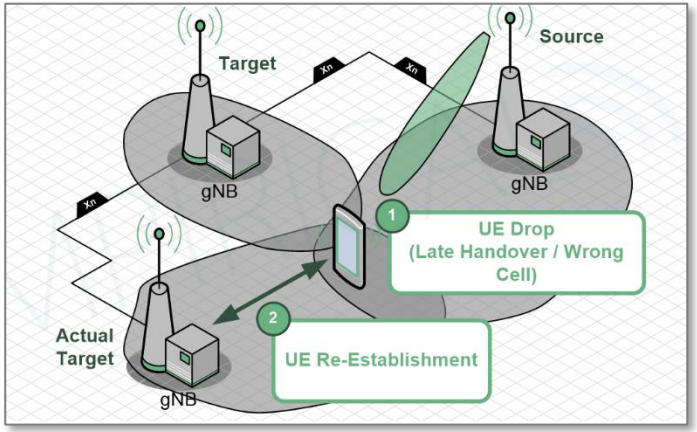
Amin Sadrabadi, H, , N. Ardalani, H., Bakhshi (2022, April). An enhanced LTE handover scheme for high-speed railway application. *Trans Emerging Tel Tech*. 2022; 33(4):e4404a.
Nugent P. (2022, October). Minimizing Handover Failures in 5G. [Online Available] https://www.mpirical.com/blog/minimizing-handover-failures-in-5g

Resilient 5G network for train (continued)

1st challenge: resilient session Handover (HO)

- Foreseeable (triggered by distance/power)
- Keeping the continuity of service (+Reliability + Availability)





2nd challenge: connection Re-establishment (RE)

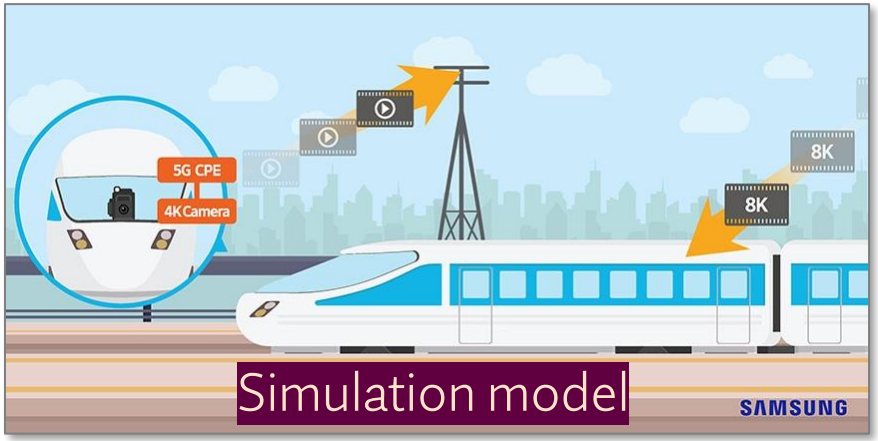
- Passive action (when losing connection)
- Decreasing down time of service (+Availability)

Amin Sadrabadi, H, , N. Ardalani, H., Bakhshi (2022, April). An enhanced LTE handover scheme for high-speed railway application. *Trans Emerging Tel Tech*. 2022; 33(4):e4404a.
Nugent P. (2022, October). Minimizing Handover Failures in 5G. [Online Available] https://www.mpirical.com/blog/minimizing-handover-failures-in-5g

Objective : estimate network service availability and reliability

- Elements
- Behaviors
- Model
- Metrics

Input data



Simulation model

Estimated values

Objective : estimate network service availability and reliability

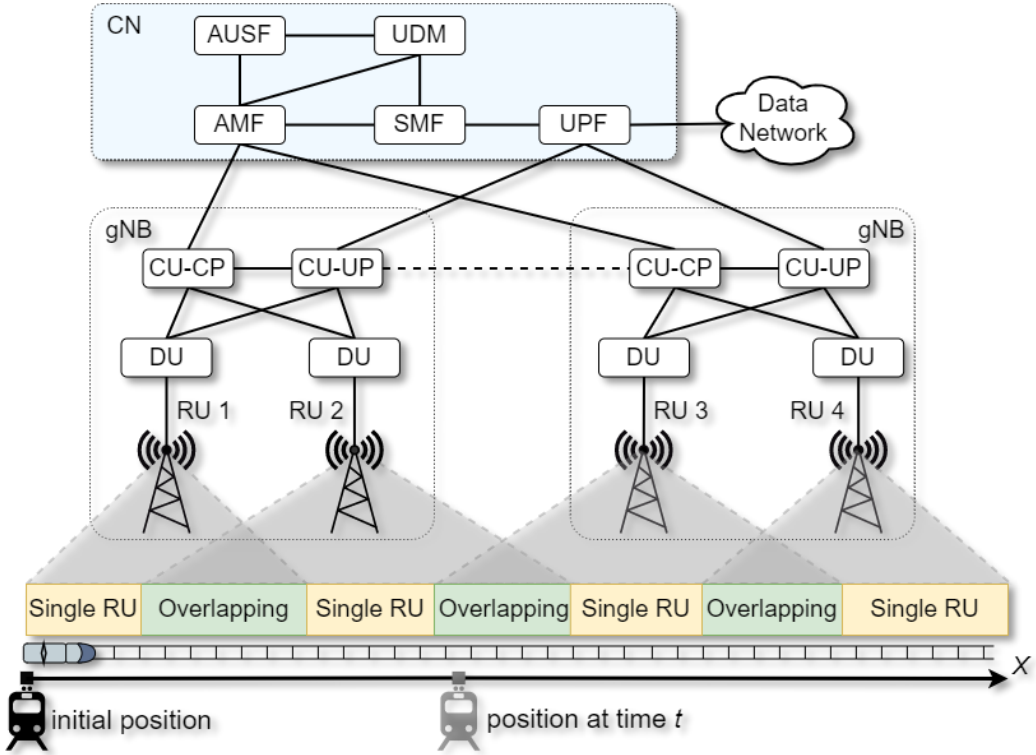
- Elements

The train(moving end-user)

In Radio Access Network:
- Radio Unit (physical equipment)
- Distributed Unit(Server + Microservices)
- Centralized Unit(Server + Microservices)

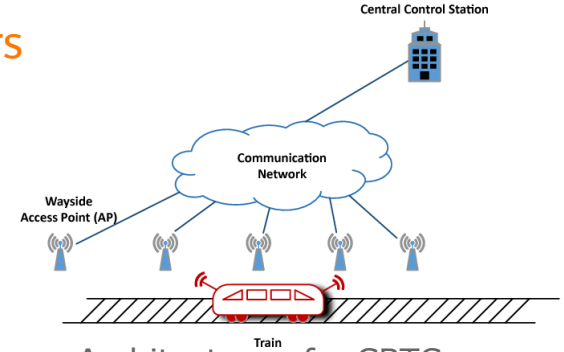
In Core Network:
- Aggregated centralized physical resource
- AMF(Microservices)
- SMF(Microservices)
- UPF(Microservices)
- ...

- Behaviors
- Model
- Metrics



Objective : estimate network service availability and reliability

- Elements
- **Behaviors**
- Model
- Metrics



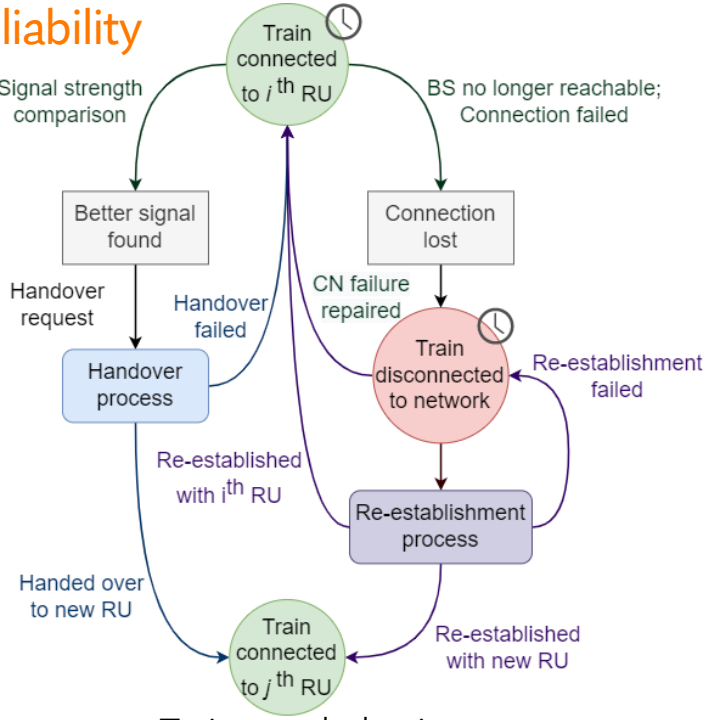
Architecture of a CBTC system.

In function of position

1. Detect better signal
2. Try handover
3. Connect to RU

In failure

4. Detect connection loss
5. Try re-establishing
6. Re-connect to RU



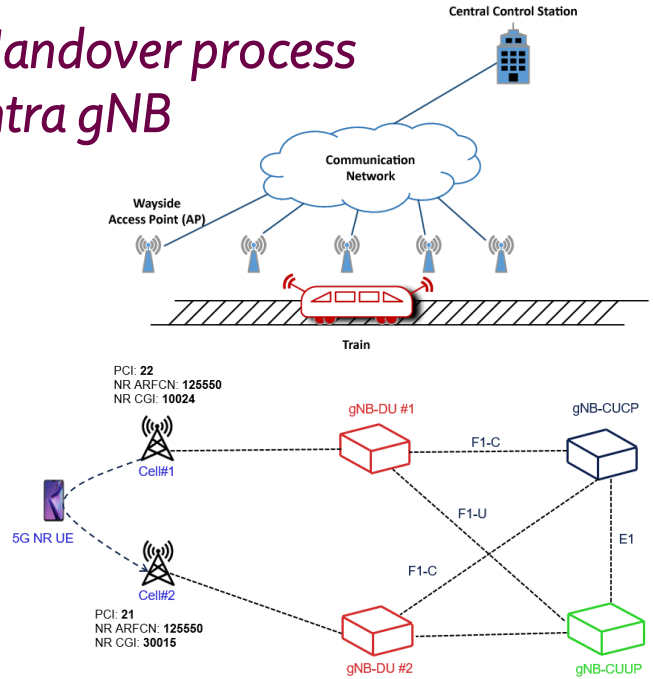
Train user behavior

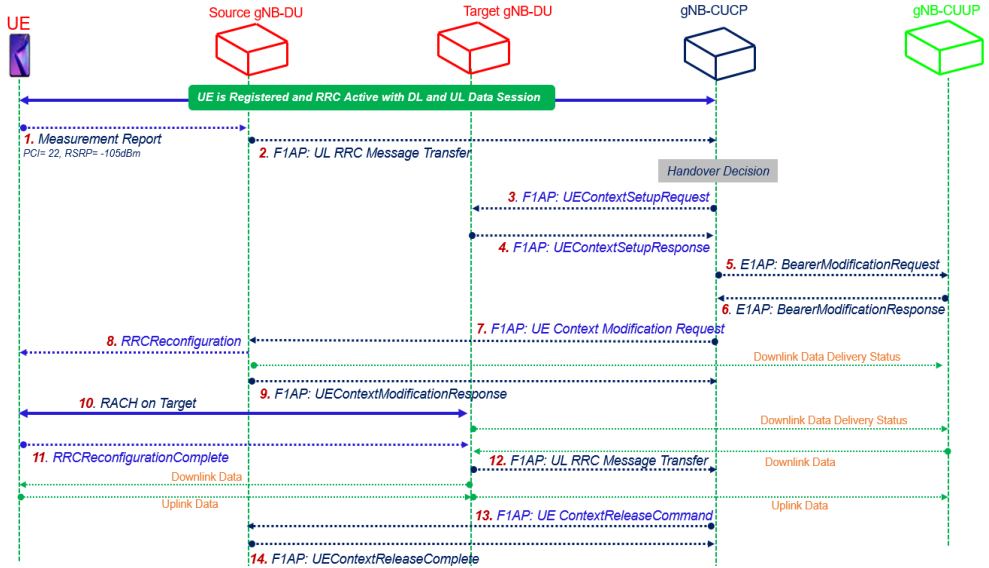
Chan, M. Y., Baroudi, S., Siu, J., & Liebeherr, J. (2017, September). Measurement-based handover method for communication-based train control systems. In 2017 IEEE 86th Vehicular Technology Conference (VTC-Fall) , pp. 1-6.

Objective : estimate network service availability and reliability

- Elements
- Behaviors

Handover process Intra gNB



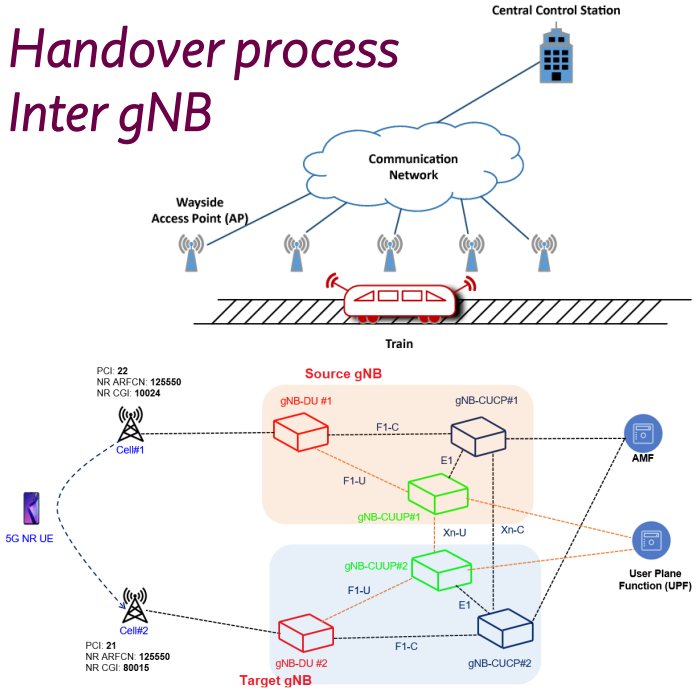


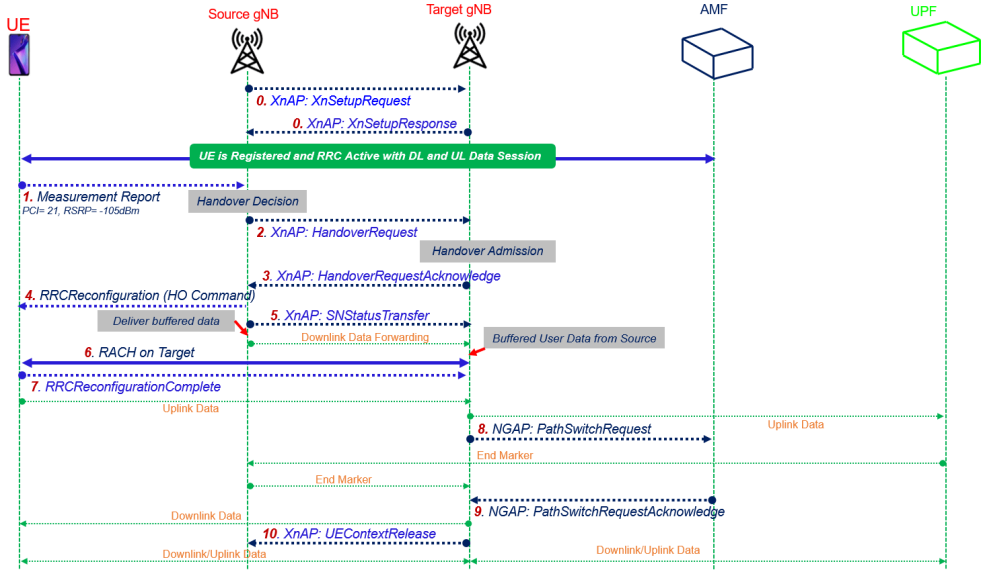
Handover process call flow

Objective : estimate network service availability and reliability

- Elements
- Behaviors

Handover process Inter gNB



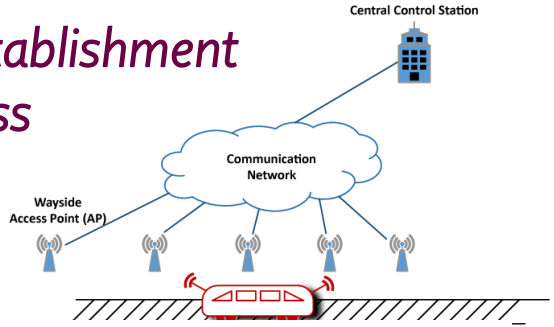


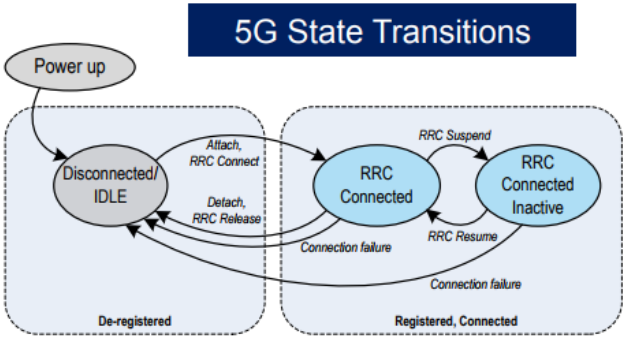
Handover process call flow

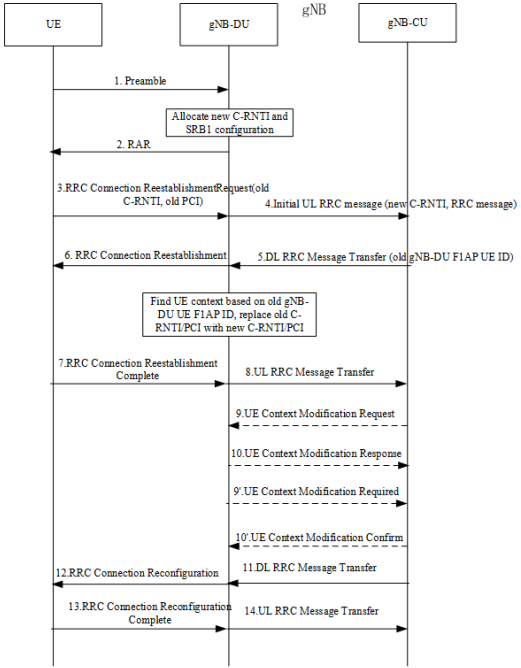
Objective : estimate network service availability and reliability

- Elements
- Behaviors

Re-establishment process







Re-establishment process call flow

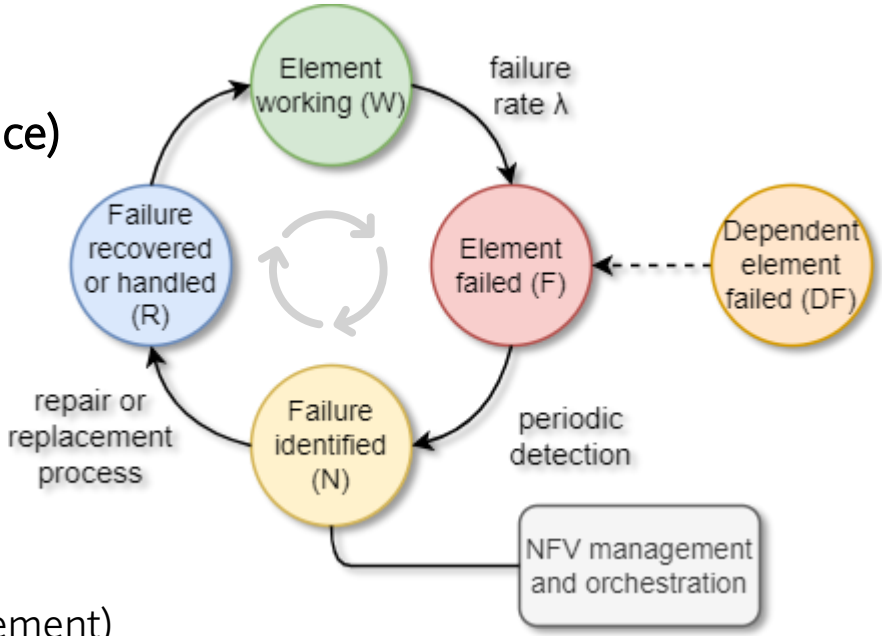
3GPP. (2020, November).3GPP TS 38.401 release 16, 5G; NG-RAN; Architecture description.

Objective : estimate network service availability and reliability

- Elements
- Behaviors

Virtual Element (Microservice)
Failure rate (weekly)
Detection (NFV-MANO)
Restart (few seconds)

Physical Infrastructure
Failure rate (yearly)
Detection (NFV-MANO)
Repair (manually/replacement)



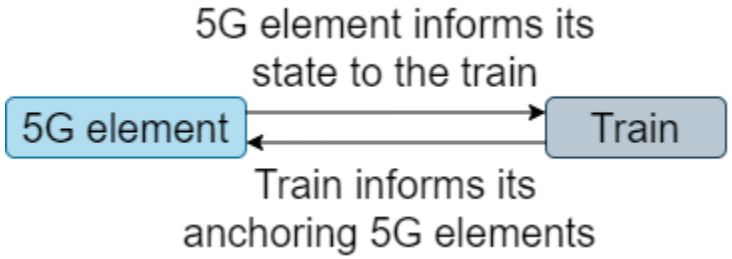
Network element behavior

- Model
- Metrics

Objective : estimate network service availability and reliability

- Elements
- Behaviors
- Model

Failure information;
Handover conformation;
Reconnection conformation;
...



Handover require (changing radio base station);
Reconnection require;
...

- Metrics

Objective : estimate network service availability and reliability

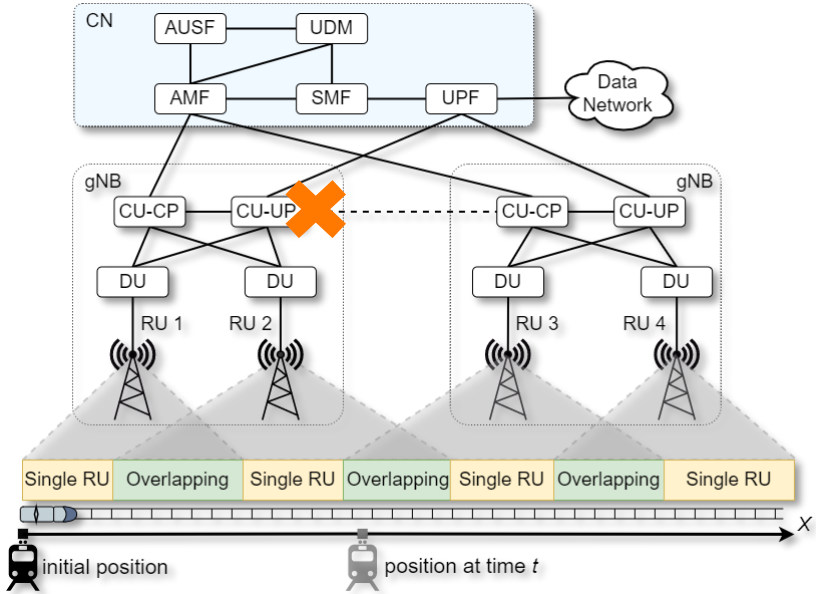
- Elements
- Behaviors
- Model
- Metrics

Providing connection to the train 7d x 24h wherever the train locates.
Offering more than consumers expect.

Network availability: the value of the amount of time the operator can provide end-to end (E2E) service everywhere by using the deployed network, divided by the total time.

Network reliability: the ability of the network to continuously provide E2E connection everywhere in a considered area.

We measure network reliability using the Mean Time To Failure (MTTF) of the network system.



Objective : estimate network service availability and reliability

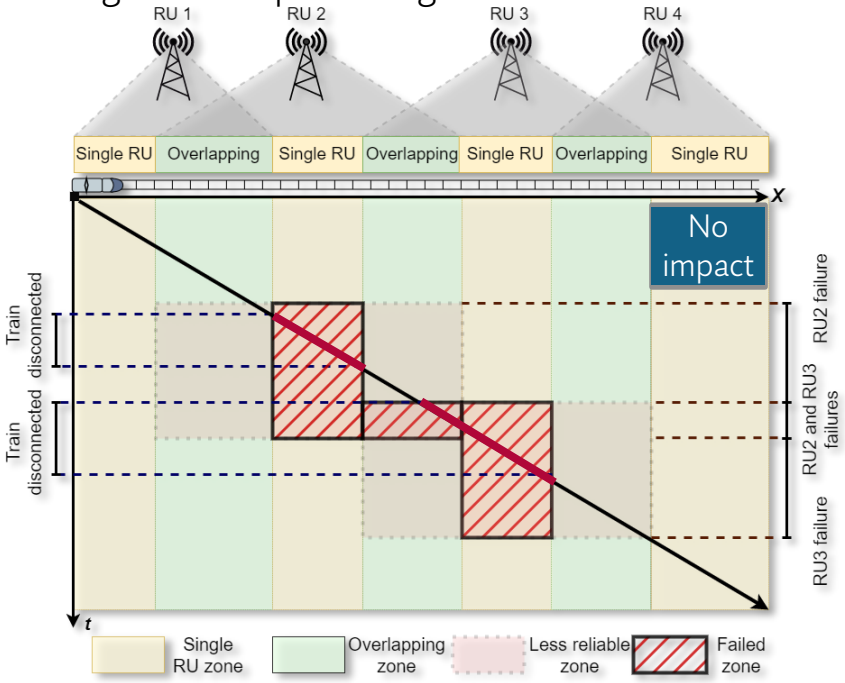
- Elements
- Behaviors
- Model
- Metrics

Using the service from where the train is located.
Consuming less than provider gives.

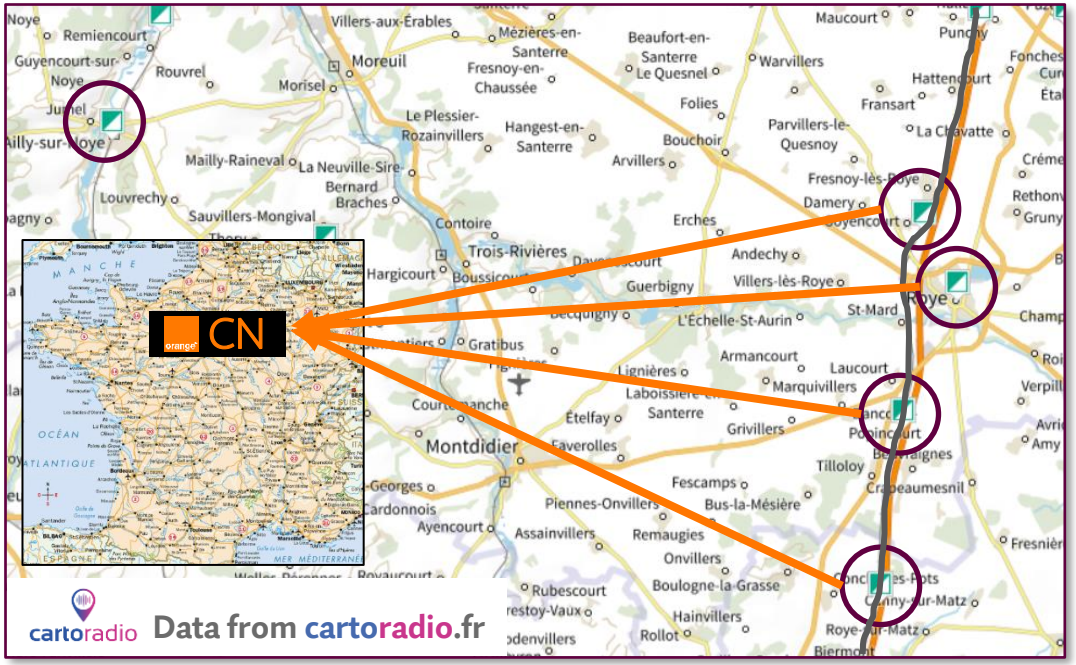
Train network communication service availability: the value of the amount of time the E2E communication service is delivered, divided by the amount of time.

Train network communication service reliability: the ability of the communication service to perform as required for a given time interval.

We describe it with MTTF of the service.



Current GSM-R positions along the railway



Radio Base Station along the railway

Distribution of Base Station:

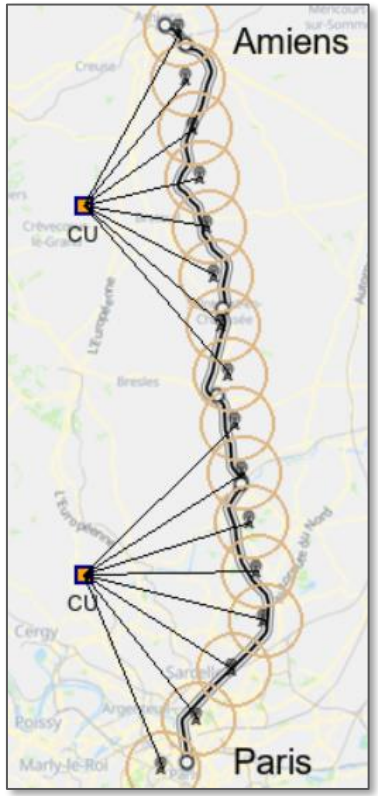
- From 1 km to 10 km
- Environment information is missing

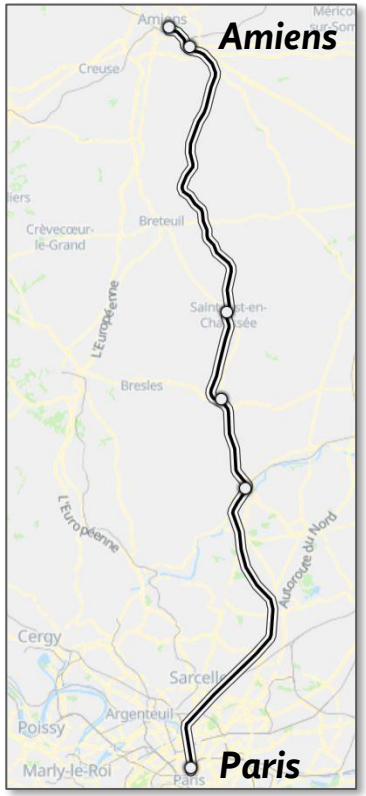
Covering area

- Some locations can be covered by 2/3+ base station (intersection)
- Some locations has no gNB redundancy (rural, less frequent line.) → *Economical aspect: decide when turning on*

A rail line between Amiens Paris about 100 km

Parameter	Interval	Value
Nb of RU/DU	6-100	16
Cover radius	1-10 km	5 km
Nb of CU	1-20	2
Redundancy		
. DU server	0-2	0
. CU standby	0-2	0
. CN standby	0-2	0
Speed	50-500 km/h	200 km/h





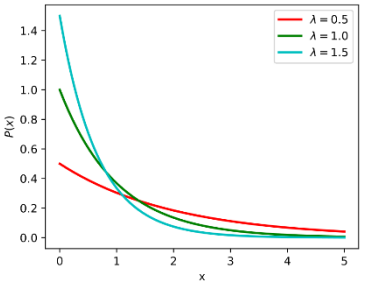
Itinerary Paris ←→Amiens

Stochastic events

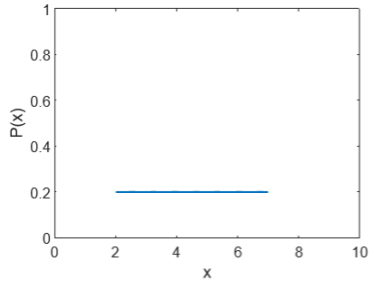
- Physical infrastructure failure
  - Exponentially distributed failure time
  - Randomly detect + fixed repair time (long)
- Virtual component failure
  - Exponentially distributed failure time
  - Randomly detect + Fixed repair time

Designated events

- A designated failure at a designated time

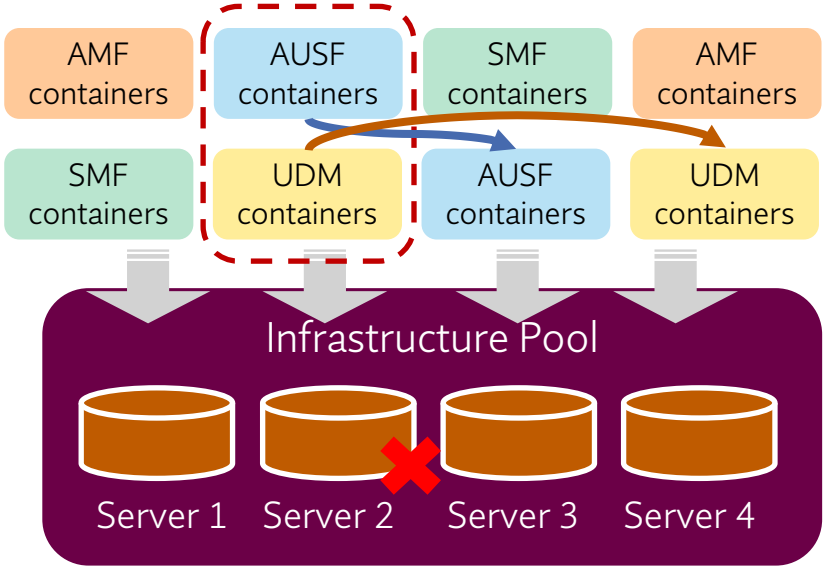


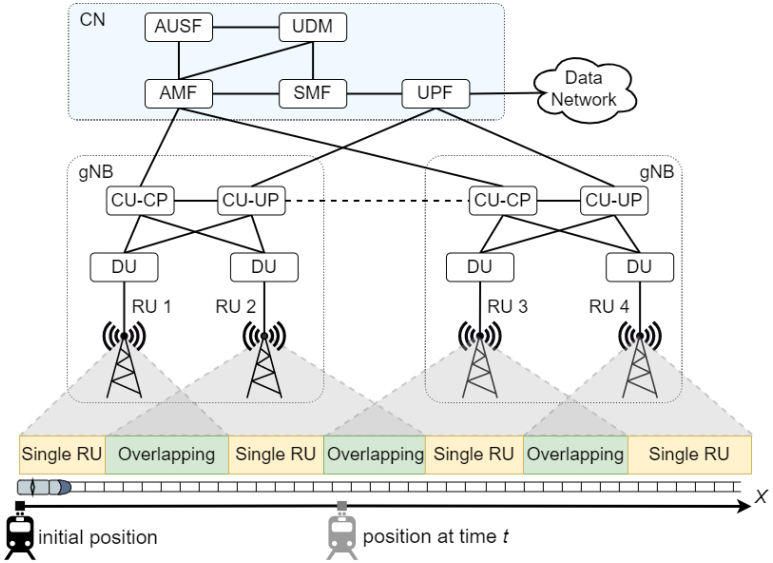
Exponential distribution



Uniform distribution

Failure without impact

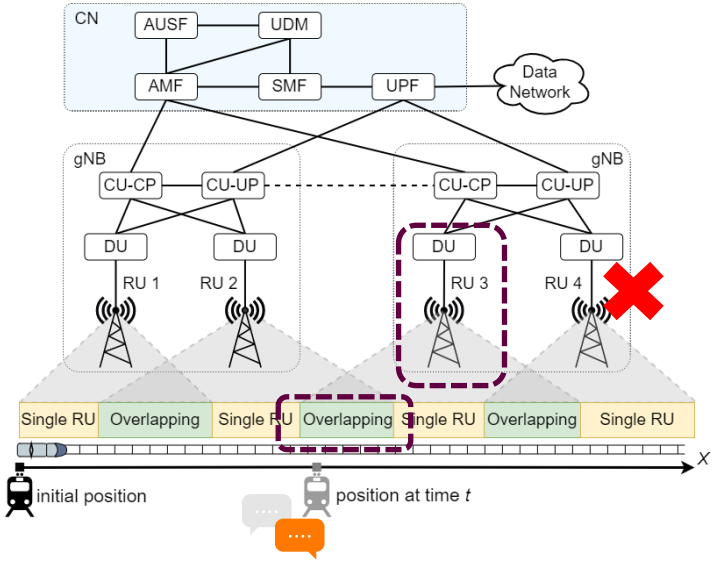




Anti-affinity strategy save the network from failure

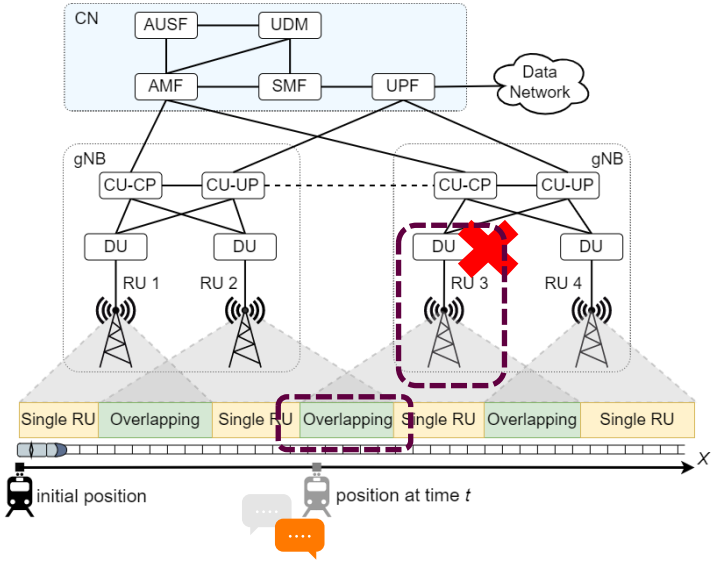
Failure only impacting network (not user)

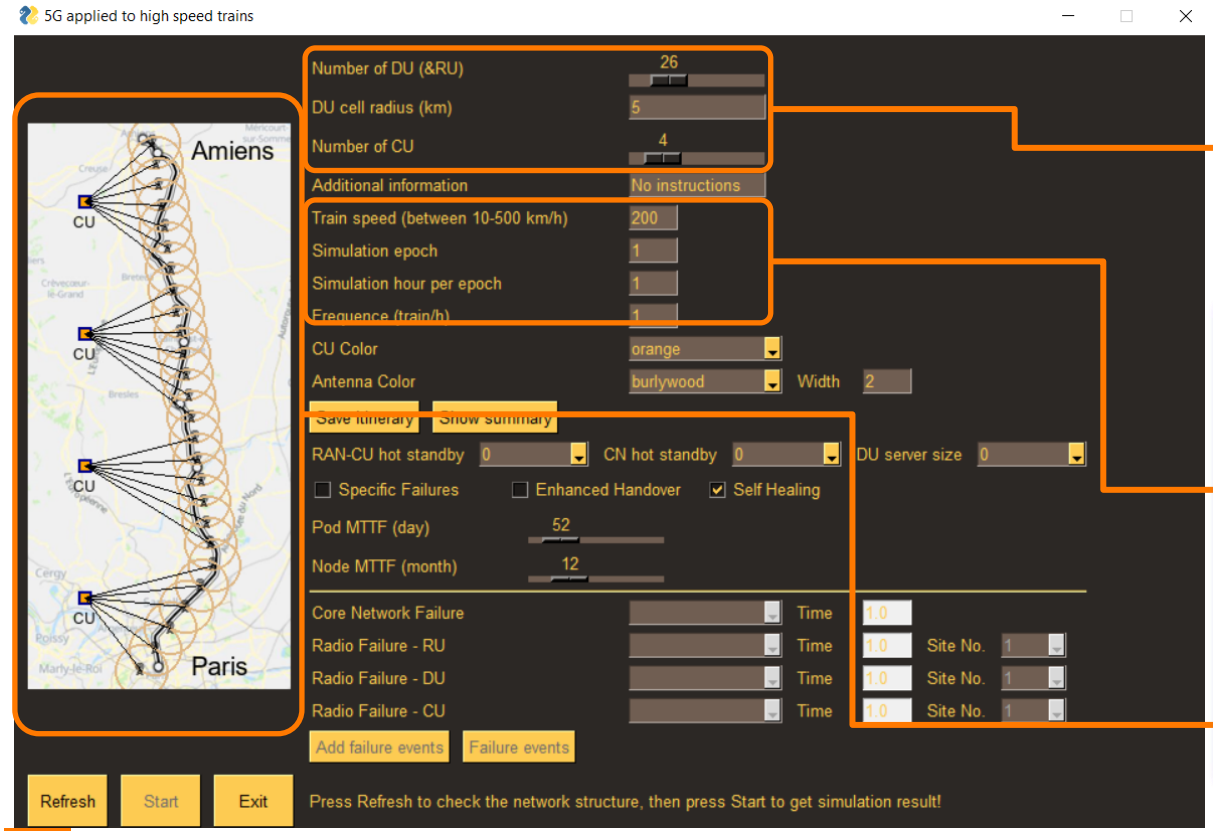
- Train at time t, running in zone 4 and it is connected to RU3
- RU4 fails, as a result, Orange cannot provide service to zone 7
- The failure of RU4 does not impact train service
- The failure of RU4 will not impact train service if repaired before train getting into zone 7



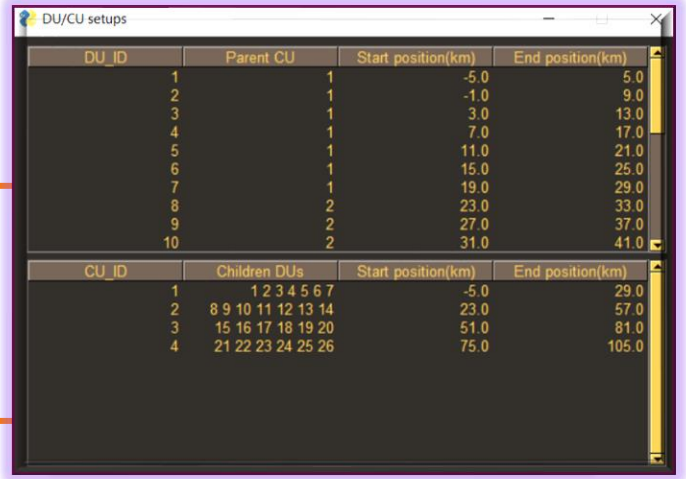
Failure impacting both network and service

- Train at time t, running in zone 4
- DU3 fails, Orange fails to provide network in zone 5
- If the train is connected to RU2
  - The Handover process will not be done
- If the train is already attached to RU3 before failure
  - The connection ends and UE try to re-establish a connection using RU 2



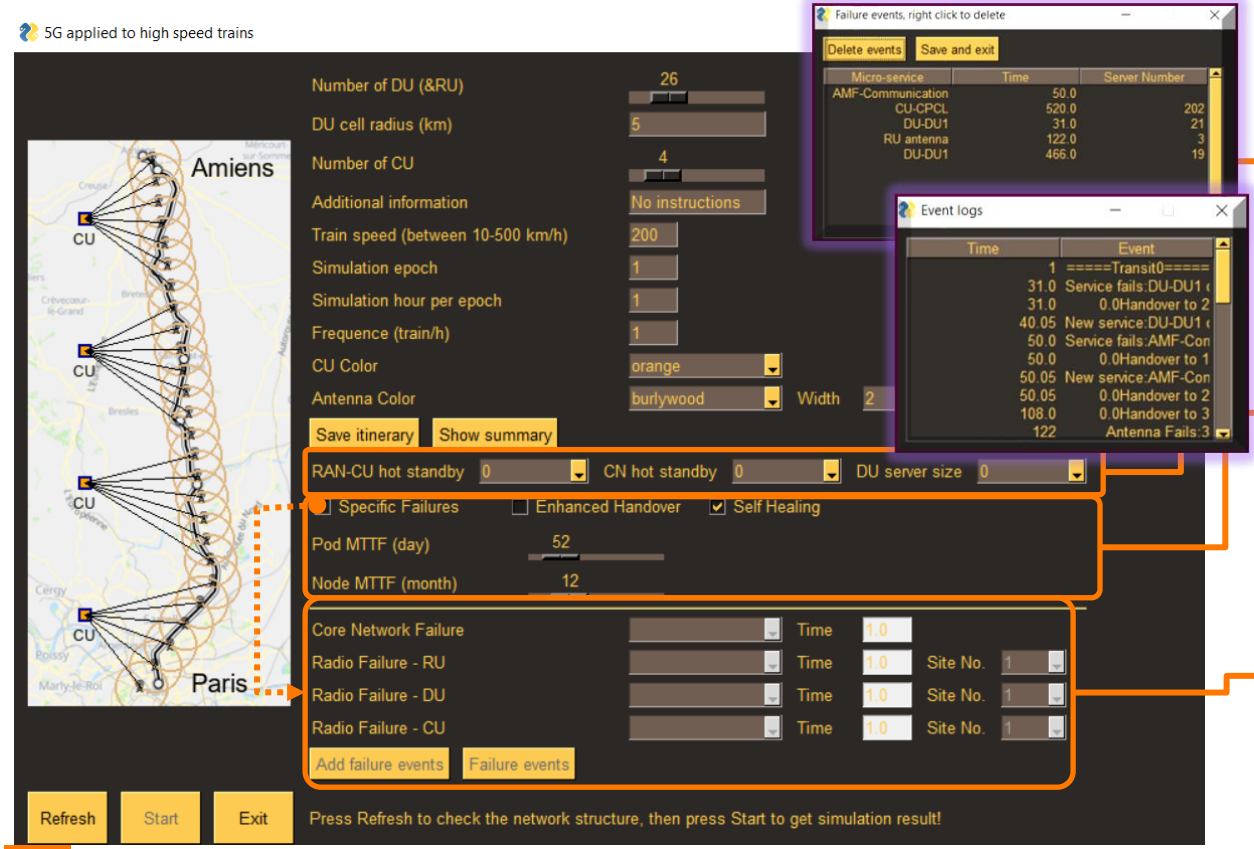


Configure Radio Access Network:
- Number of Base station RU, DU
- Coverage distance
- Number of CU (gNB)



DU_ID	Parent CU	Start position(km)	End position(km)
1	1	-5.0	5.0
2	1	-1.0	9.0
3	1	3.0	13.0
4	1	7.0	17.0
5	1	11.0	21.0
6	1	15.0	25.0
7	1	19.0	29.0
8	2	23.0	33.0
9	2	27.0	37.0
10	2	31.0	41.0

CU_ID	Children DUs	Start position(km)	End position(km)
1	1 2 3 4 5 6 7	-5.0	29.0
2	8 9 10 11 12 13 14	23.0	57.0
3	15 16 17 18 19 20	51.0	81.0
4	21 22 23 24 25 26	75.0	105.0



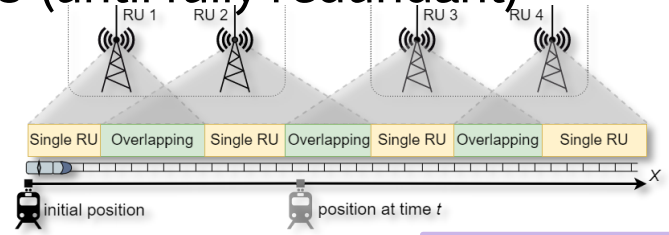
Network element redundancy:
- DU server
- CU replicas
- CN VNF replicas

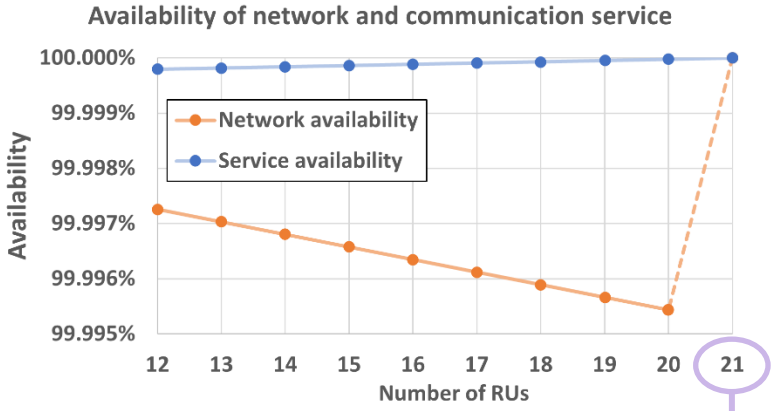
Network functionality:
- Enable repair process
- Set failure rate for servers and virtual containers (pods)

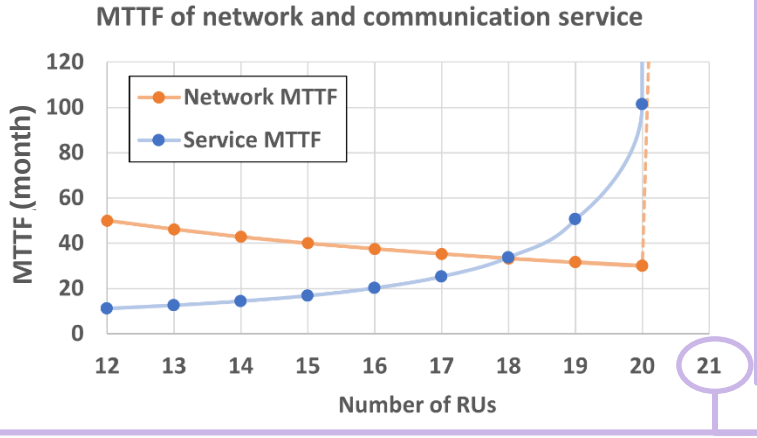
Designated failures:
- Define specific failure events:
  - Time
  - Element
  - One at a time

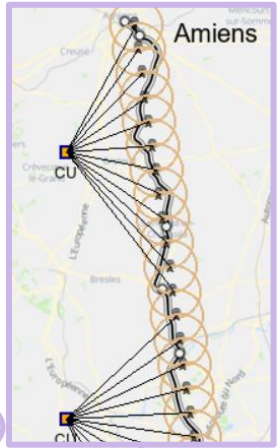
Random element failure only on RU

- Network availability decreases with number of RU (until fully redundant)
  - Number of single connection zone increases
- Service availability increases with number of RU
  - Overlapping zone area increases



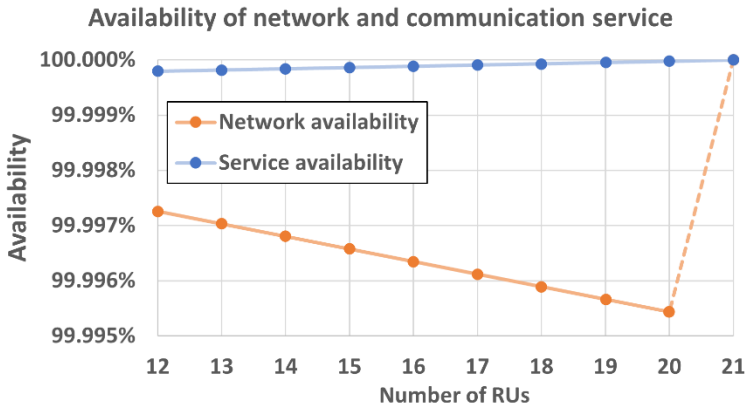


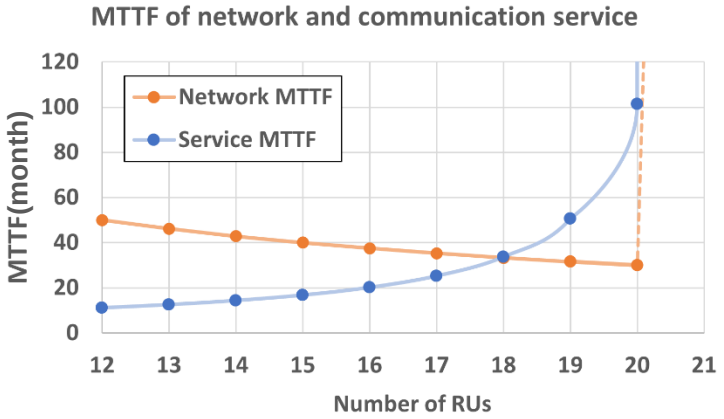




Random element failure only on RU

- Network reliability decreases with number of RU (until fully redundant)
  - Number of single connection zone increases
- Service reliability increases with number of RU
  - Overlapping zone increases, MTTF increases



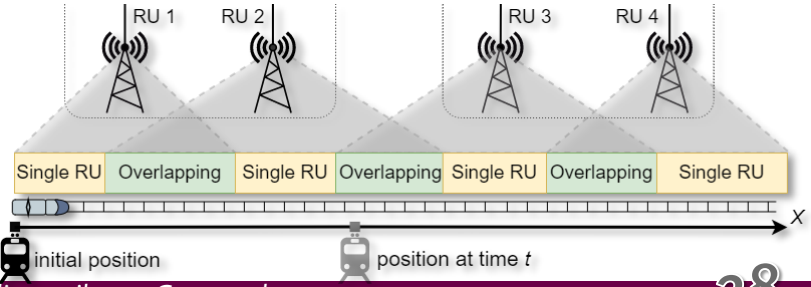


Random failure everywhere in the network

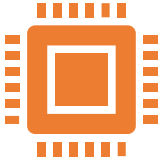
Handover and Re-establishment are considered

- Network availability decreases with number of
  - Due to failure caused by increasing number of single connection area
- Service availability increases with number of RU
  - Thanks to re-establishment and handover
- Network reliability decreases with number of RU
  - Failures happen more frequently
- Service reliability **decreases** with number of RU
  - Service interrupted due to failure caused by increasing number of elements

Number of RUs	Network availability	Network MTTF (hours)	Service availability	Service MTTF (hours)
12	99.86058%	55	99.99456%	359
13	99.84895%	52	99.99512%	344
14	99.83789%	50	99.99571%	333
15	99.82612%	48	99.99628%	319
16	99.81485%	46	99.99686%	308
17	99.80219%	44	99.99742%	298
18	99.79151%	42	99.99801%	288
19	99.78031%	41	99.99859%	279
20	99.76875%	39	99.99917%	270



- A more complicated scenario combined both Control Plane & User Plane is considered
- Perspectives from provider and consumer on availability and reliability are compared
- A platform is built for investigating the impact of network structure on network performance



Degrading and maintenance process:

Physical device may have aging process with a changing failure rate

Grouped maintenance can be considered

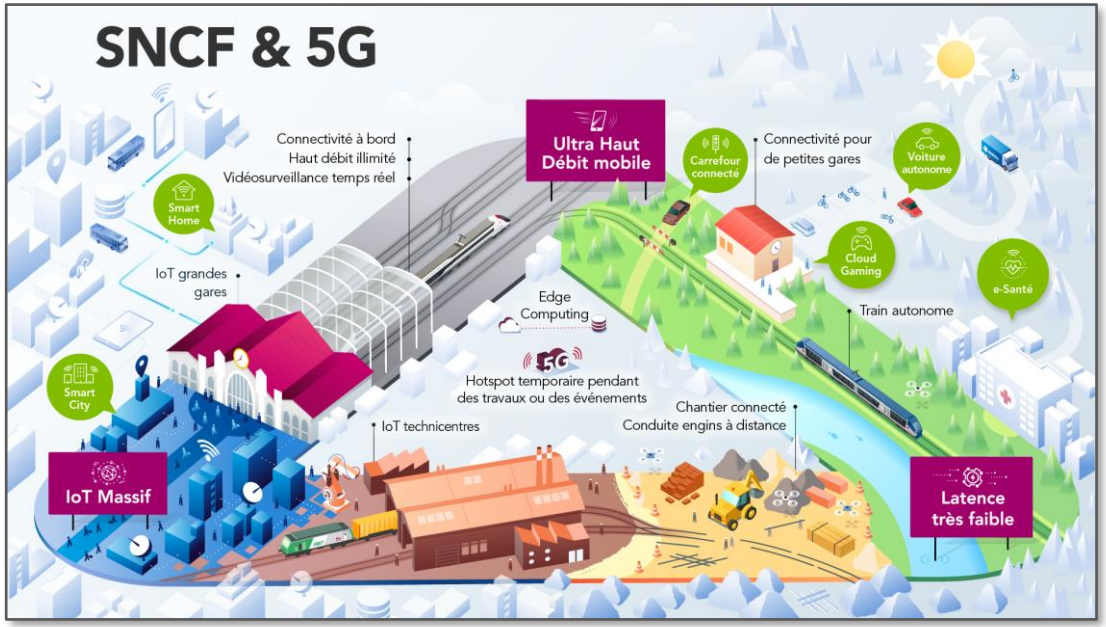
Environment Challenges:

Radio signal power can be largely reduced inside a tunnel, in mountain area, or on rainy days

High speed Challenges:

Time to carry out a handover may be short, the HO process can be disturbed

Railway scenario meets 5G



In 2021, SNCF designed ecosystem with over thirty 5G usages:
autonomous train,
real-time station surveillance,
temporary hotspots...

5G and 6G are on the route...

SNCF Numérique. (July 2021) Télécoms : SNCF explore les usages de la 5G dans son écosystème. [online]https://numerique.sncf.com/actualites/telecoms-sncf-explore-les-usages-de-la-5g-dans-son-ecosysteme/

Thanks

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