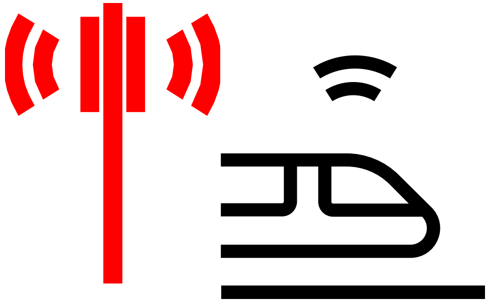
Executive Summary Phase 3

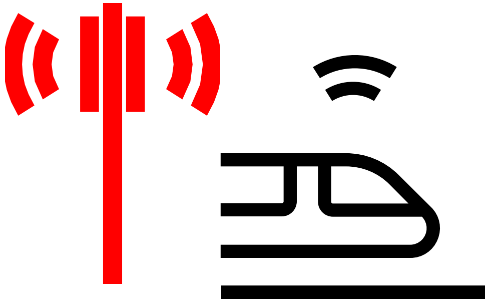
SBB CFF FFS



Ericsson AG

11th December 2019

Agenda

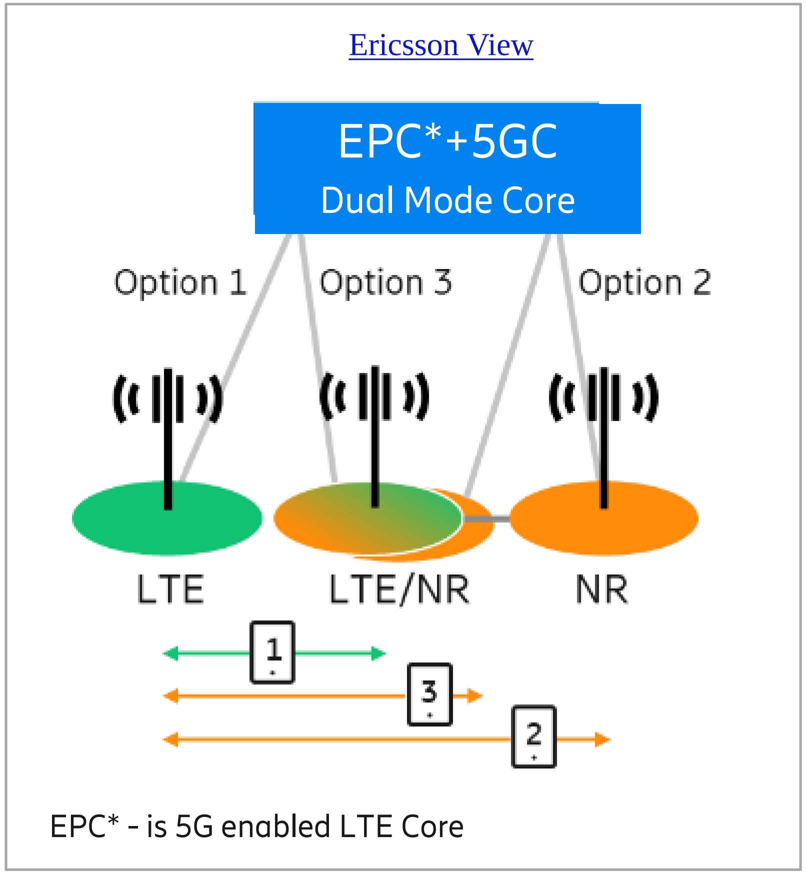


Agenda

1. Moving from 4G to 5G
2. End to End Architecture and Benefits
3. Radio Dimensioning Process and Results
4. Radio Planning Validation
5. Radio Redundancy Configurations
6. Wrap Up

Standardization & Industry: moving from 4G to 5G

Benefits of 5G and NR (New Radio)

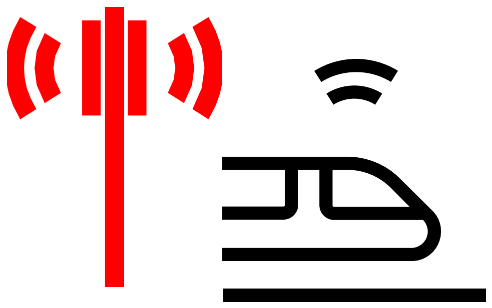


Enhanced Network Slicing support
- E2E network slice identifier (NSSAI)
- Improved network slice isolation (NSSF)
- Multiple network slices per device

Service Based Architecture for agility
- IT architecture principles
- Allows fast new service creation
- Extensibility and reuse

Less complex RAN and UE architecture
- Reduced signaling
- Lower control-plane latency
- Less complex RAN and UE architecture

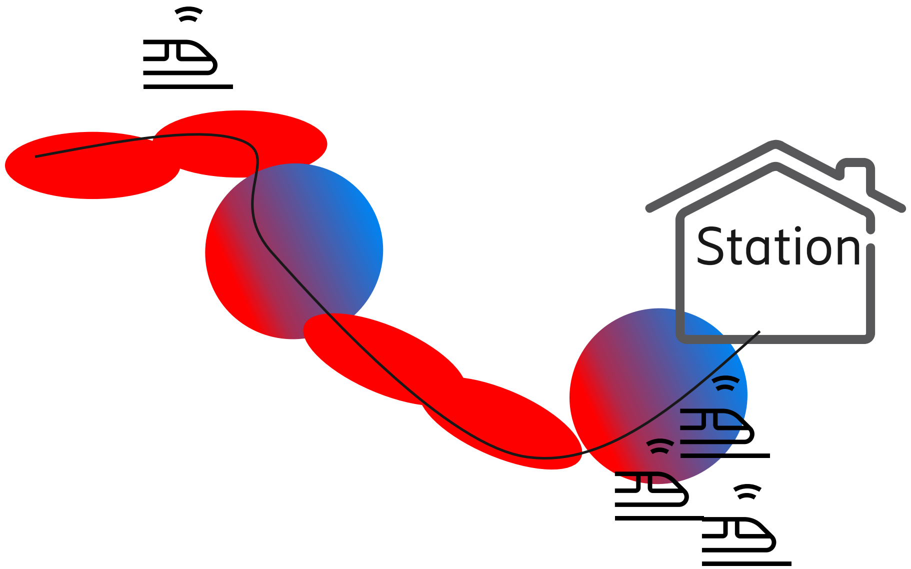
Target architecture for new use cases and innovation
- Industry eco-system focus on 5GC and NR
- One Core for all access type (including fixed, Wi-Fi)



Agenda

Network Sharing

Where?



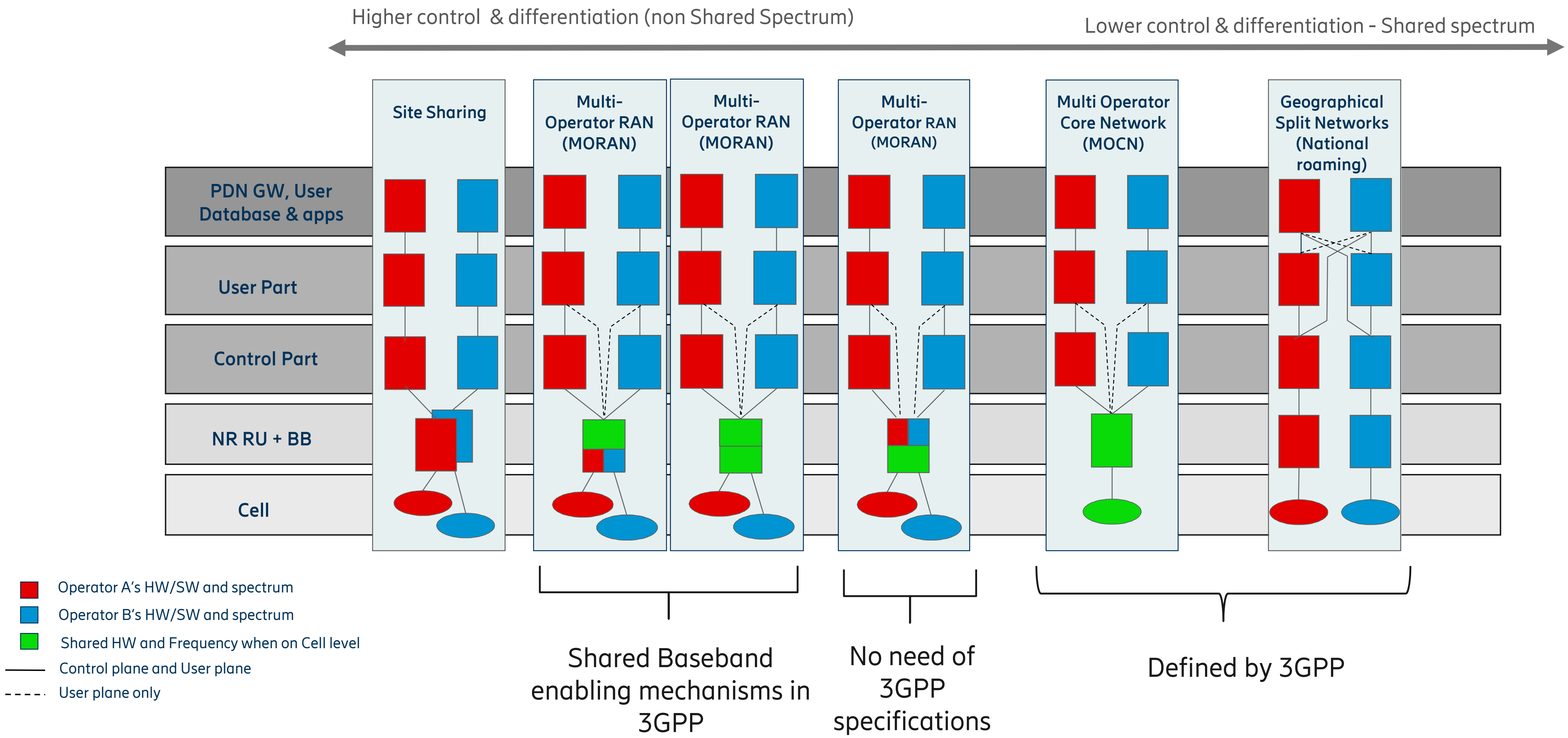
SBB MNO

How?

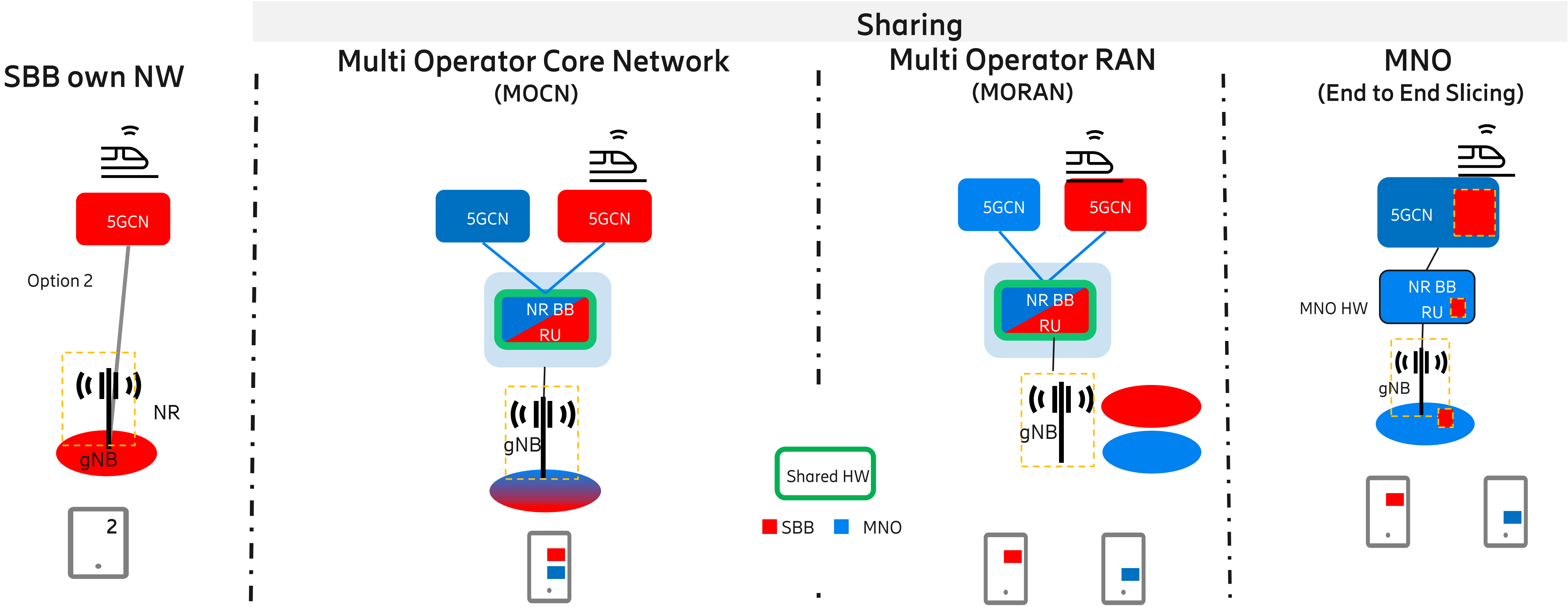
Higher control & differentiation ↔ Lower control & differentiation

Passive Sharing	Active sharing but not RAN related	Active sharing including RAN but not spectrum sharing	Active sharing including RAN and shared spectrum

If network sharing, these are the options



SBB Network Scenarios



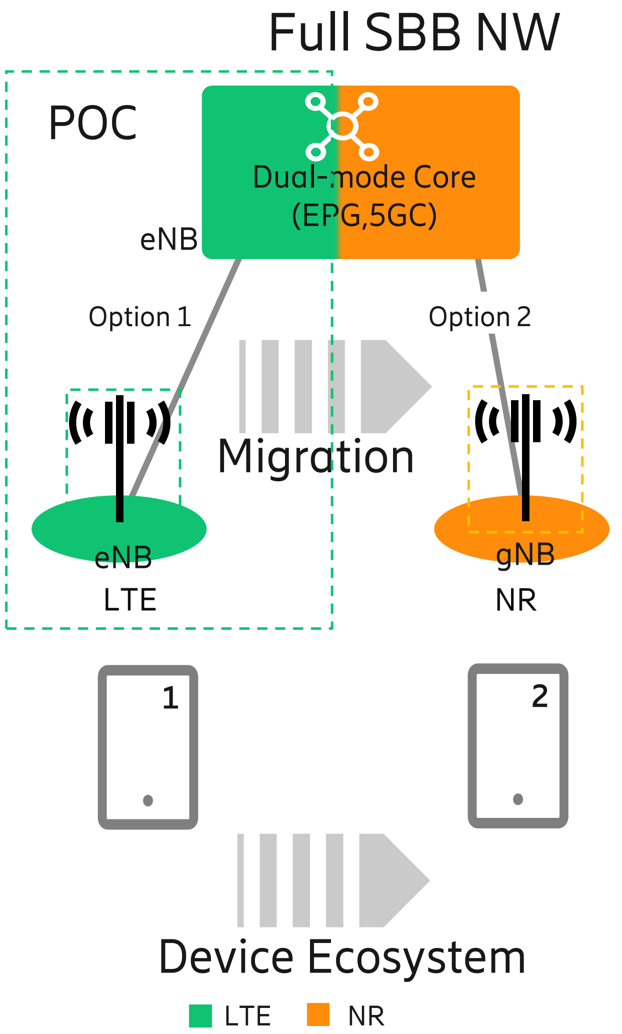
- SBB own Spectrum

- Combined Spectrum of SBB & MNO
- Separate Core Networks
- Optional common radio hardware

- SBB own spectrum
- Separate Core Networks
- Common radio hardware

- MNO Spectrum
- Service access through MNO slice

SBB own Network Scenario



- Start with LTE POC (Option 1 in 3GPP) and reuse the current available UE ecosystem
- Migrate to final target with full NR radio network and 5GC core when NR UE ecosystem is ready
- SW migration from LTE to 5G with:
  - Dual-mode Core
  - SW upgrade on radio side
- Full Independence from MNO
- For non critical services, a MNO slice can be still used

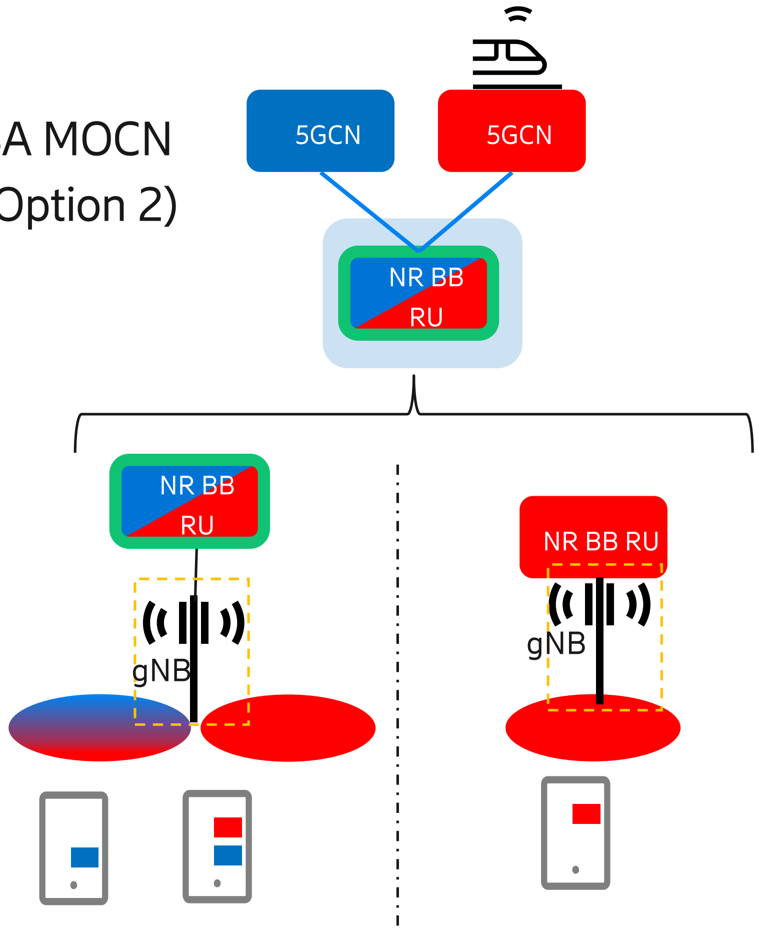
Nominal dimensioning example:

- Frequency 1900 MHz
- Bandwidth 10 MHz
- EIRP 40dBm
- TDD 50:50
- UL Cell Edge Thrp. 5Mbps
- Redundancy*
- ISD 2.41km (h=16m) / 2.76km (h=22m)

*Redundancy: The redundant layer is in Standby mode and is prepared to go ON AIR on demand

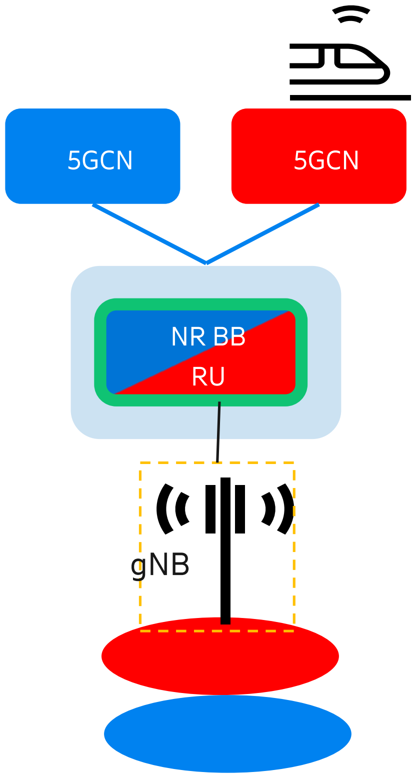
Multi Operator Core Network (MOCN) Scenario

SA MOCN
(Option 2)



- A MOCN scenario requires close cooperation and governance with MNO.
- Radio network components should come from the same vendor to benefit from:
  - Carrier aggregation
  - Features that rely on lower protocol levels (eg. CoMP)
- A common deployment needs to be agreed with MNO and SW level compliance between Radio and Core needs verification
- Radio dimensioning results (Intercell distance) for an SBB owned network can be considered as an upper bound

Multi Operator Radio Access Network (MORAN)



— A MORAN scenario creates a dependancy on MNO:
  — Same coverage area
  — Same SW level required (may be hard to match the align SBB and MNO requirements)
  — Infrastructure management

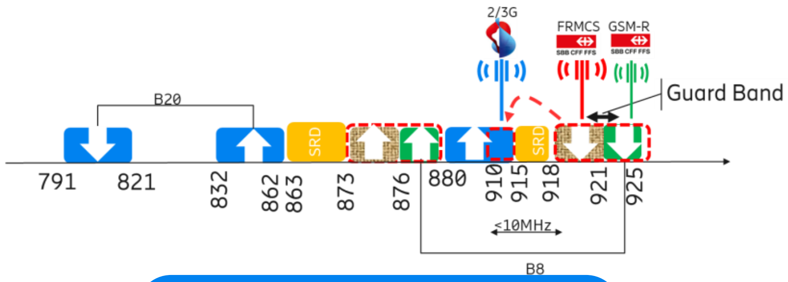
— Independent Radio spectrum

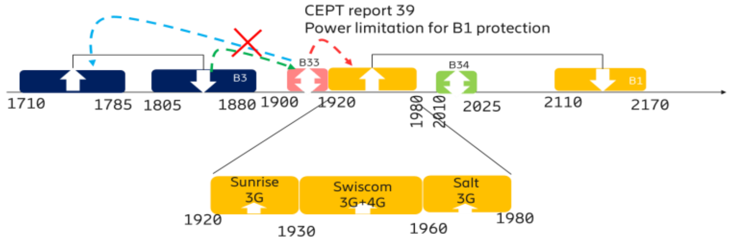
— This scenario provides mainly CAPEX saving without radio performance benefits

Agenda

SBB Own spectrum and maximum power options

Powers based on PT1 draft

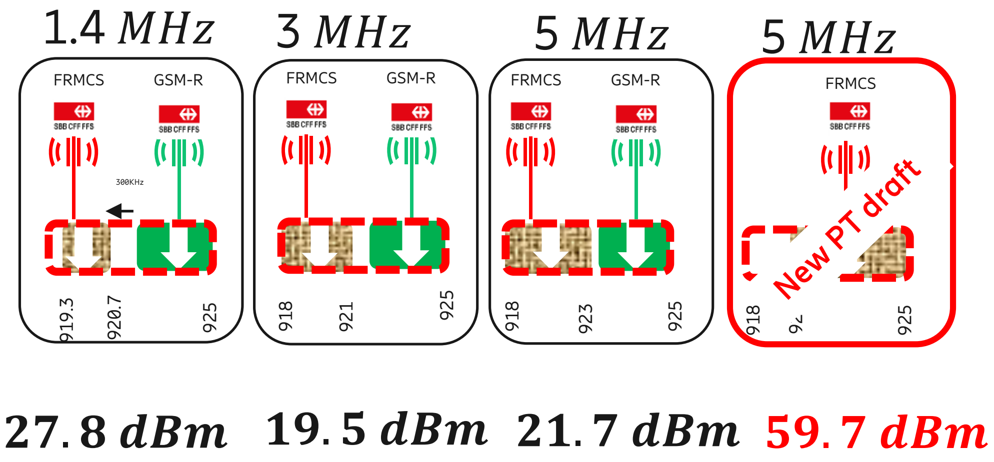




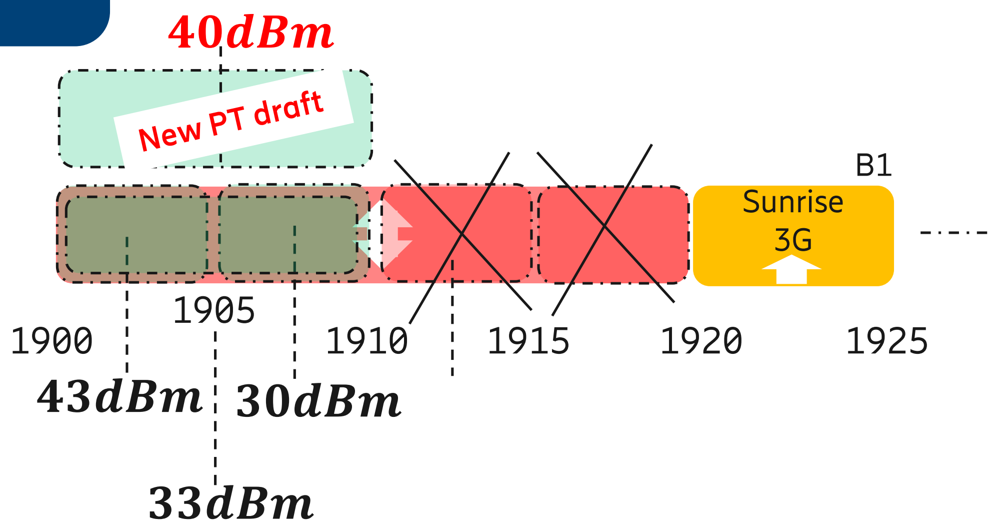
900MHz coexistence and Blocking B8 Band

1900MHz coexistence and Blocking B1 Band

Scenario selection and max EIRP evaluation



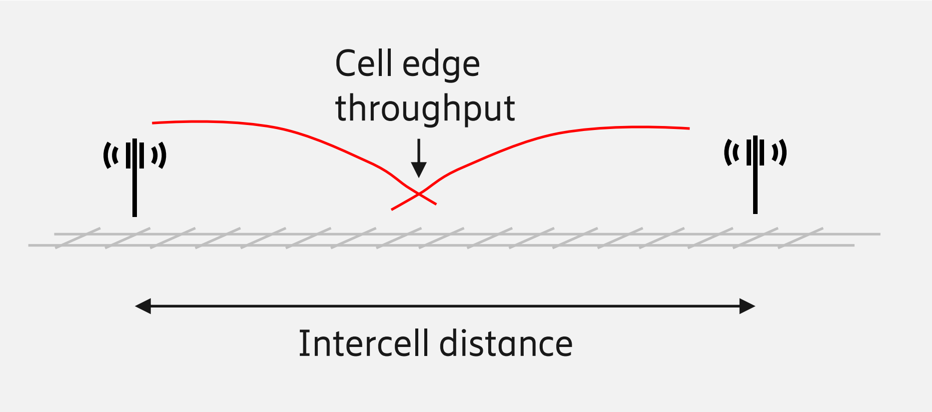
EIRP



5G RF Simulation Methodology for SBB Spectrum

Methodology similar as in SBB Phase 2:

- Set **link budget parameters**
  - Power, antenna gains, losses, margins etc.
- Set **target Uplink (UL) Cell Edge Throughput targets**
  - 1,3,5, [10] Mbps
- Solve for maximum propagation loss to achieve the target UL throughput:
  - Allow limiting by Downlink control channel coverage
- From maximum propagation loss:
  - Set nominal antenna height and propagation model
  - Calculate inter-cell distances for different antenna heights
- The powers (EIRP) used are based on last PT1 draft report
  - 1900MHz, MCL based on 100m site spacing (worst case scenario)
  - as per TS.137.104, Table 6.6.2.1-1



Maximum Intercell Distance

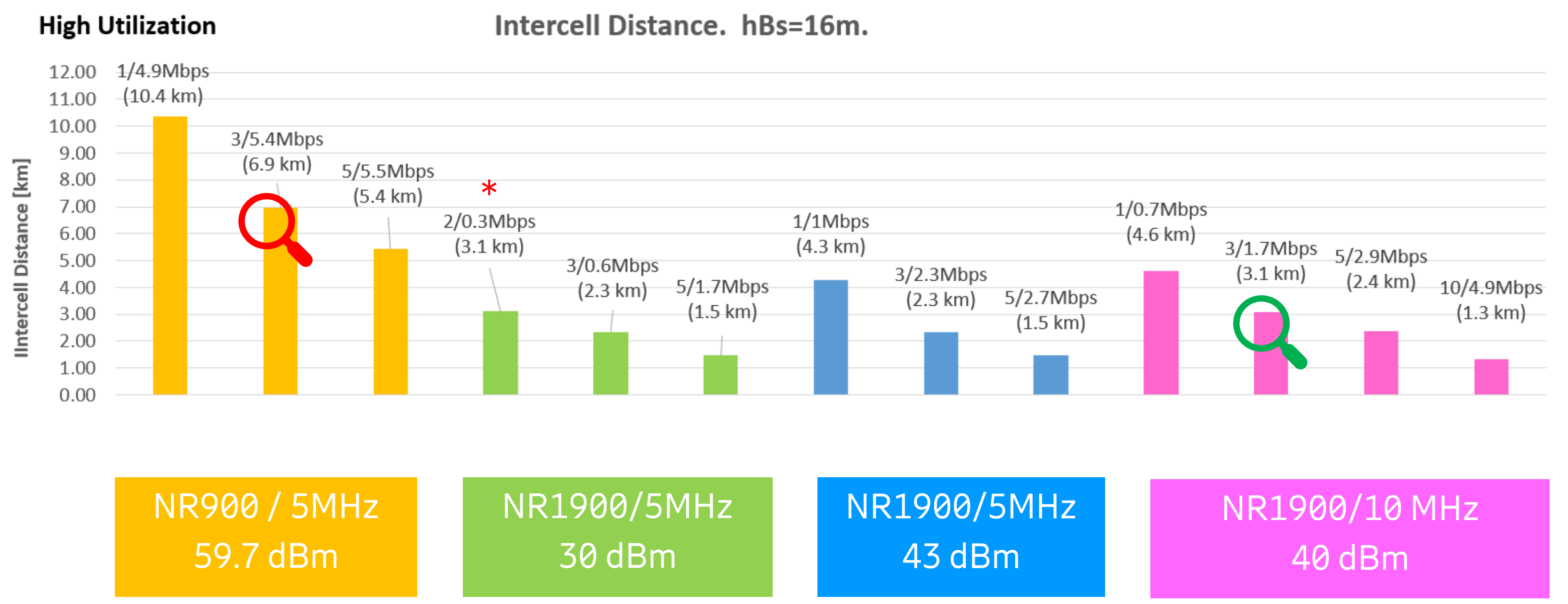
High Utilization, Suburban, 16m BS height

900 MHz/5MHz FDD

- Intercell distance ~7 km for (3 Mbps cell edge UL)
- Not limited by DL control channels with increased DL power (59.7 dBm)

1900MHz/10 MHz TDD 50:50

- Intercell distance ~3.1 km
- 3 Mbps cell edge UL, 1.7 Mbps DL



- Downlink control channel limited scenarios shown with *
- UL/DL bitrates shown as labels
- Power is EIRP

Maximum Intercell Distance – different TDD pattern

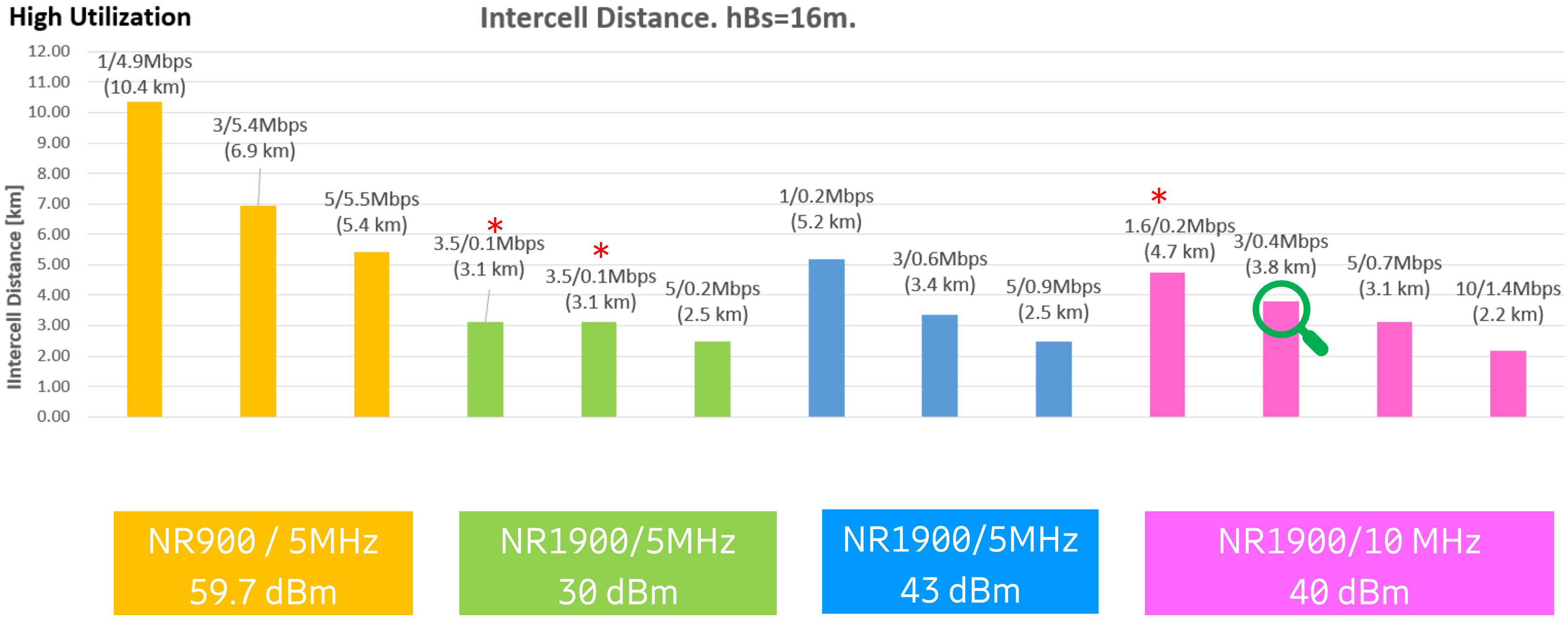
High Utilization, Suburban, 16m BS height

Different TDD pattern

- 80% of TDD slots are used for Uplink

1900MHZ/10 MHz TDD 20:80

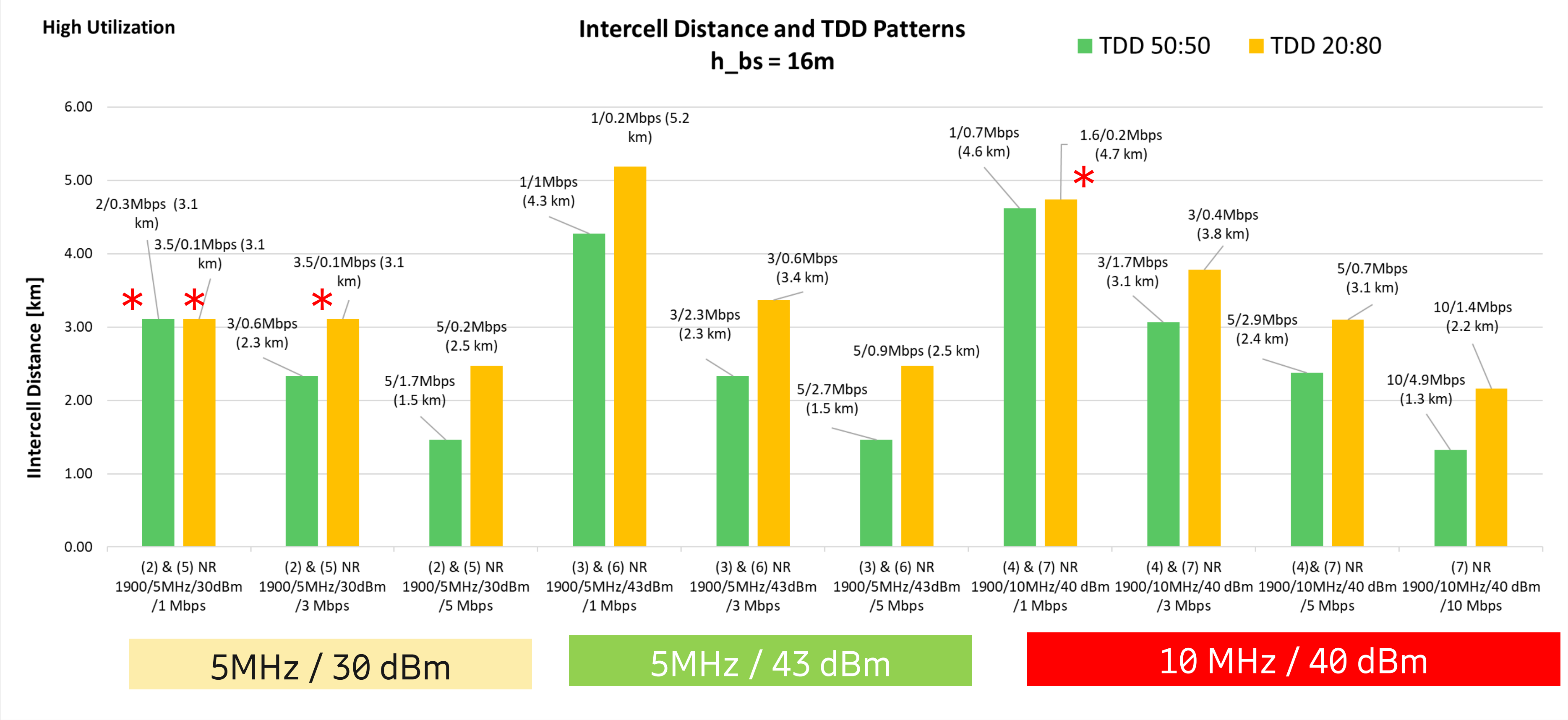
- Intercell distance increases from 3.1 km to 3.8 km
- 3 Mbps cell edge UL bitrate
- DL bitrates reduced (0.4 Mbps)



- Downlink control channel limited scenarios shown with *
- UL/DL bitrates shown as labels
- Power is EIRP

Intercell Distance vs TDD Patterns

1900 MHz. 16 m BS antenna height, High Loading

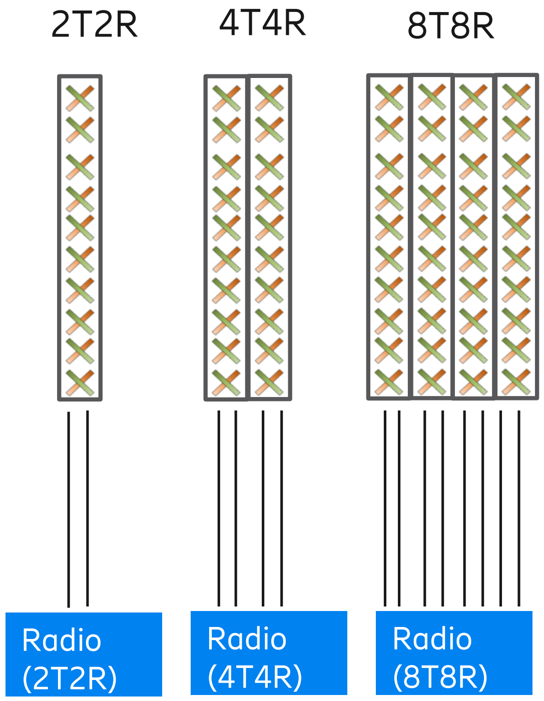


- Using a 20:80 pattern can increase uplink bitrates
  - at the expense of downlink cell edge bitrates

- Downlink control channel limited scenarios shown with *
- UL/DL bitrates shown as labels
- Power is EIRP

Impact of using different antennas
4T4R and 8T8R Radios

- 4T4R and 8T8R radio configurations can provide uplink and downlink performance improvements
- Downlink beamforming gains of approximately 3 dB and 6 dB
- However downlink powers must be reduced to keep EIRP constant
  - Limits DL throughput gains
- Potential to increase uplink coverage by approximately:
  - 3 dB (4T4R)
  - 6 dB (8T8R)
- 5G Multi User-MIMO is not applicable for general railway track coverage
  - Could be used for main stations and shunting yards for higher capacity

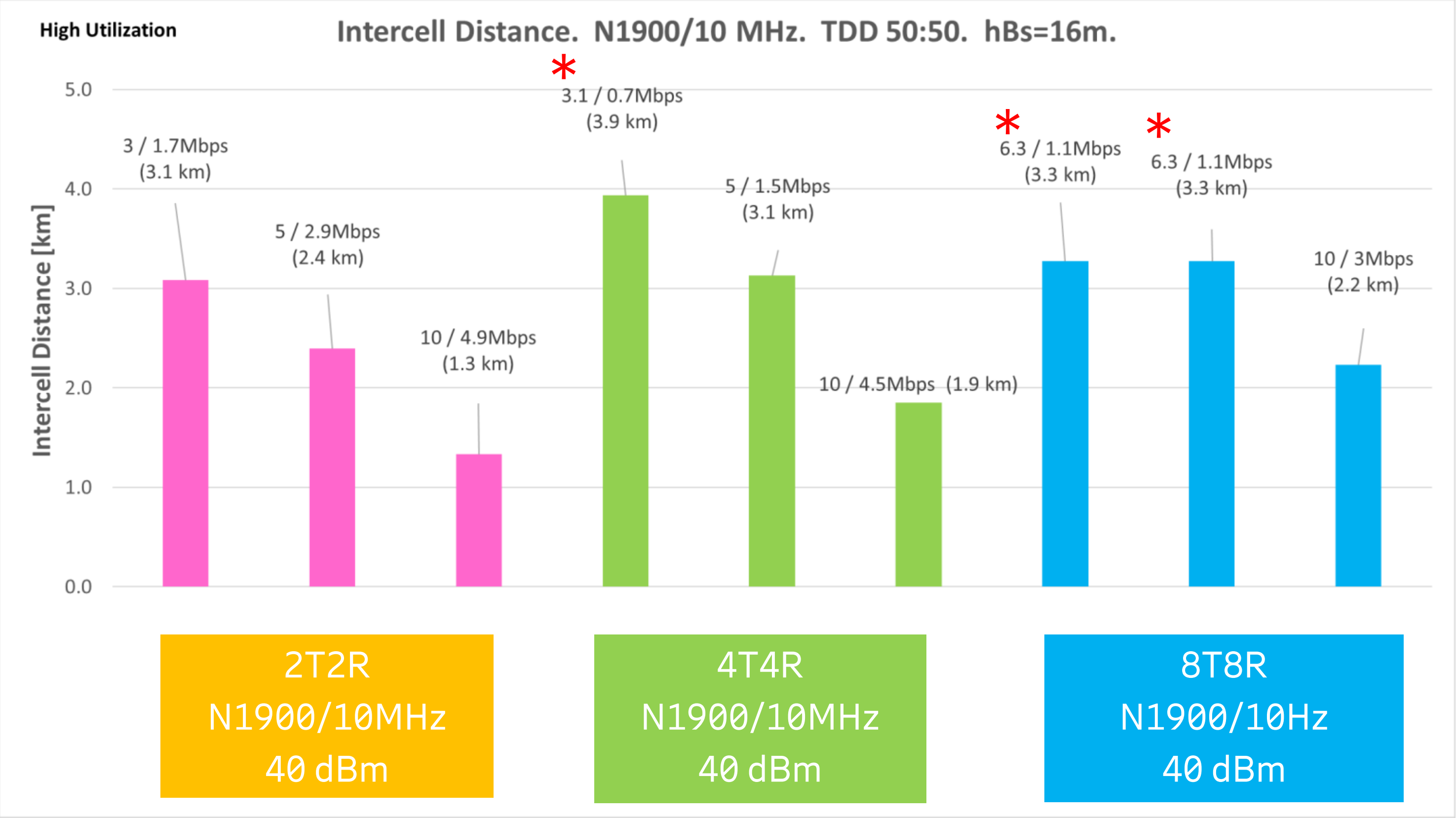


Larger antennas and more feeders are needed for 4T4R and 8T8R

Impact of using different antennas

4T4R and 8T8R Radios
N1900 /10 MHz , 40 dBm EIRP

- Some gains are possible for uplink coverage
- Downlink is impacted by EIRP restrictions
- Downlink control channels can limit coverage



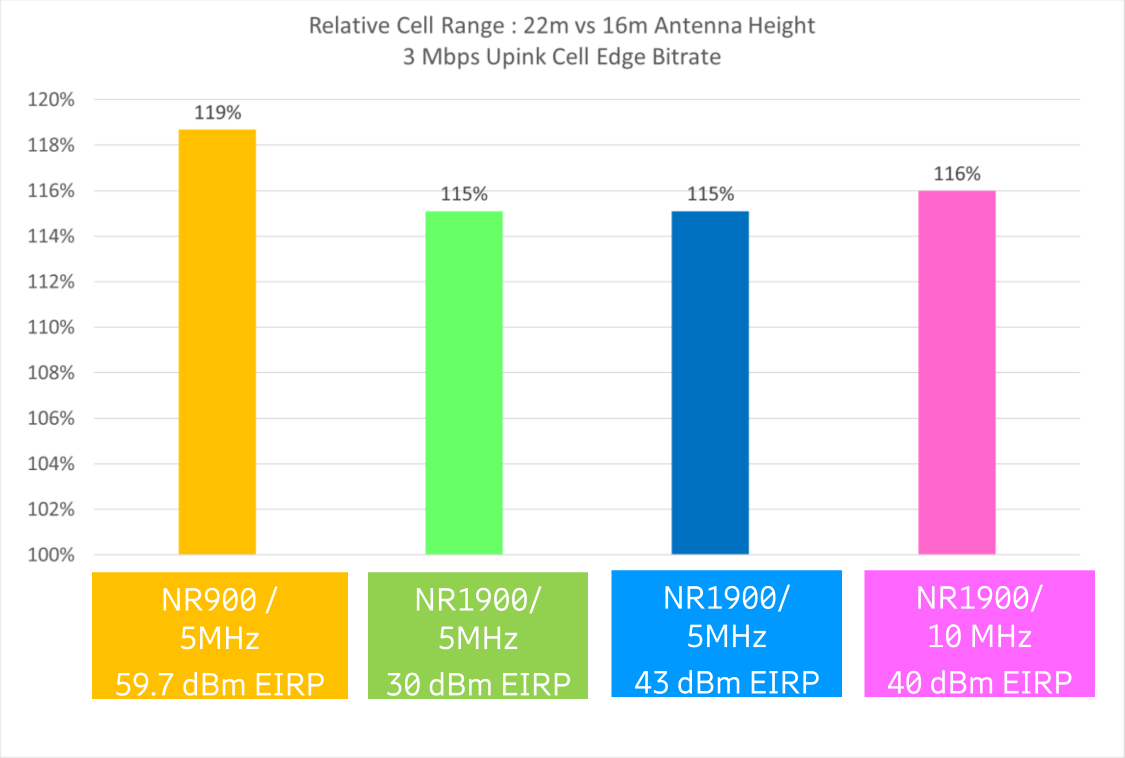
Base Station Config	Uplink Cell Edge Target	Coverage Gain over 2T2R	Notes
4T4R	3 Mbps	29%	DL CCH Limiting
	5 Mbps	31%	
	10 Mbps	39%	
8T8R	3 Mbps	6%	DL CCH Limiting
	5 Mbps	37%	DL CCH Limiting
	10 Mbps	68%	

- Downlink control channel limited scenarios shown with *
- UL/DL bitrates shown as labels
- Power is EIRP

Antenna Height Impact on Intercell distance

22m vs 16m, TDD 50:50

- Using a 22m antenna height can result in a larger cell spacing for the same uplink cell edge bitrate
- ~ 16% larger Intercell distance for NR 1900 MHz is possible for 3Mbps UL cell edge throughput



Non Line of Sight propagation model is assumed

Summary 5G radio dimensioning

- NR at 1900MHz (50:50 TDD) with 10 MHz bandwidth can be used to achieve:
  - ~3 km site spacing for a 3 Mbps uplink cell edge bitrate
- A different TDD pattern (20:80) can be used to increase uplink throughput and coverage
  - At the expense of downlink throughput
- 4T4R and 8T8R can be used to increase uplink performance
  - Downlink performance gains not achieved due to EIRP limitations
  - Larger antennas will be required

- Simulations results are derived using a proven conservative approach:
  - Maximum allowable downlink powers are based on a 100m distance to adjacent spectrum systems (CEPT & PT1).
  - Suburban propagation model used with 98% probability cell edge performance.
  - Used link performance curves based on system simulator.

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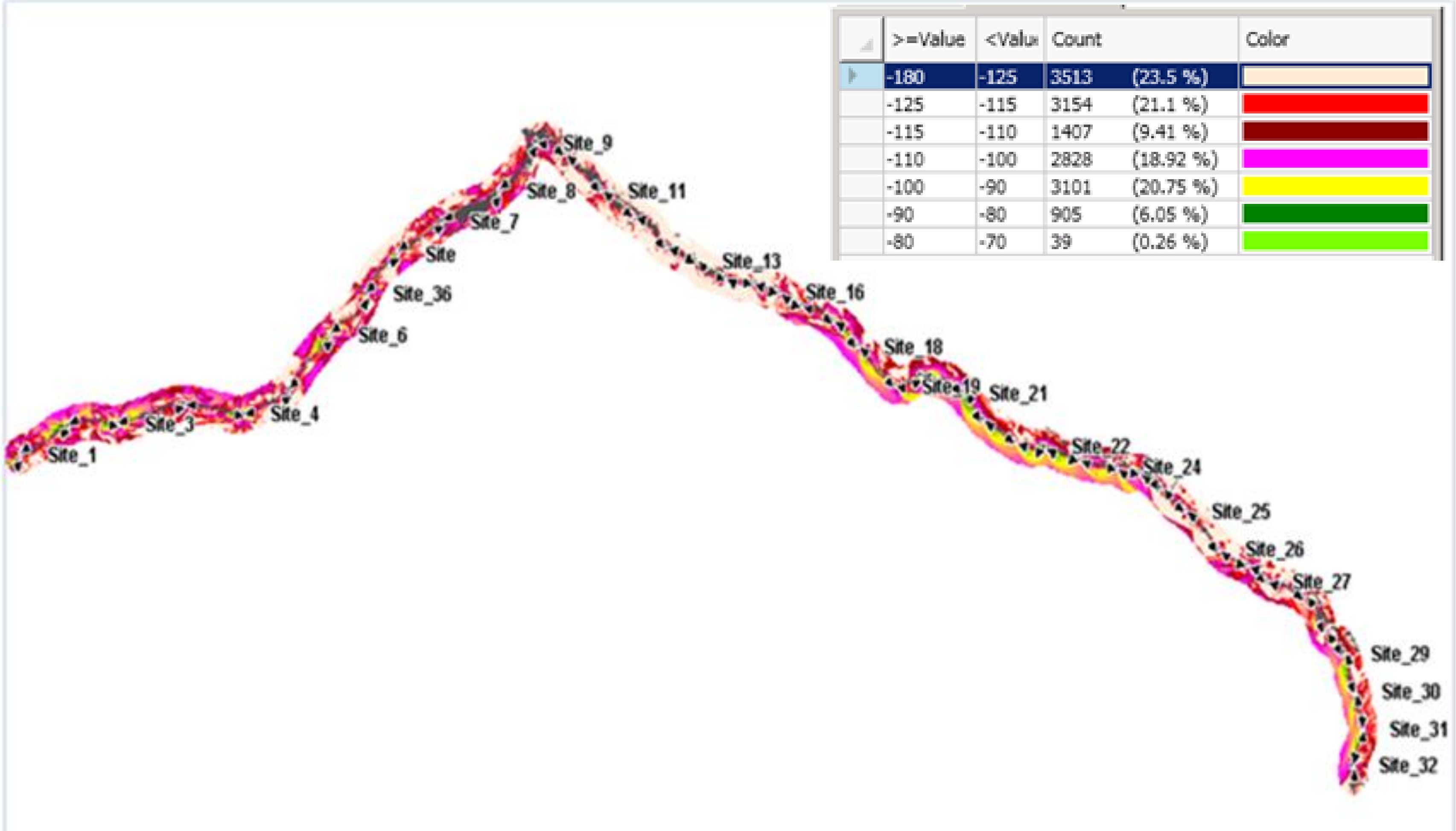
Planet Inputs and service level requirements

	2	3	4	5
Freq / BW	1900 / 10 MHz	1900 / 5 MHz	1900 / 5 MHz	900 / 5 MHz
Duplex	TDD	TDD	TDD	FDD
EIRP (Max TX Pow+Ag)	40 dBm	43 dBm	30 dBm	59.7 dBm
BS Antenna Gain	19 dBi	19 dBi	19 dBi	19 dBi
Bs Tx power	21 dBm	24 dBm	11 dBm	40.7 dBm
Bs Noise figure	2 dB	2.5 dB	2.5 dB	2 dB
DL Max Modulation	256QAM	256QAM	256QAM	256QAM
Max UE UL Modulation	64QAM	64QAM	64QAM	64QAM
UE Cable loss	3 dB	3 dB	3 dB	3 dB
Train Roof loss	5 dB	5 dB	5 dB	5 dB
UE Antenna gain	8 dBi	8 dBi	8 dBi	8 dBi
UE Noise figure	7 dB	7 dB	7 dB	7 dB
UE Tx power	23 dBm	23 dBm	23 dBm	23 dBm
UE Receivers	2	2	2	2
Jumper Loss	0.2 dB	0.2 dB	0.2 dB	0.2 dB
LNF Margin	6 dB	6 dB	6 dB	6 dB
Propagation Model	Ericsson Hata	Ericsson Hata	Ericsson Hata	Ericsson Hata
Environment	suburban	suburban	suburban	suburban
Channel Model	EVA70	EVA70	EVA70	EVA70
Cell Plan Factor	0.33	0.33	0.33	0.33
BTS Antenna H upper part	22 m / 16m	22 m / 16m	22 m / 16m	22 m / 16m
UE Antenna H	4m	4m	4m	4m
UL Loading	1/2/3 dB	1/2/3 dB	1/2/3 dB	1/2/3 dB
DL Loading	0.25/0.5/0.75	0.25/0.5/0.75	0.25/0.5/0.75	0.25/0.5/0.75
Control Channels	2 PUCCH, CFI=1	3.5 PUCCH,CFI=1	3.5 PUCCH,CFI=1	2 PUCCH, CFI=1
DL Load	25% / 50% / 75%	25% / 50% / 75%	25% / 50% / 75%	25% / 50% / 75%
UL Load	1dB / 2dB / 3dB	1dB / 2dB / 3dB	1dB / 2dB / 3dB	1dB / 2dB / 3dB
UL Tput at cell edge for 5MHz	NA	1 Mb / 3Mb / 5Mb	1 Mb / 3Mb / 5Mb	1 Mb / 3Mb / 5Mb
UL Tput at cell edge for 10MHz	1 Mb / 3Mb / 5Mb / 10 Mb	NA	NA	NA

Planet Mentum Validation
RSRP Coverage Whole Track

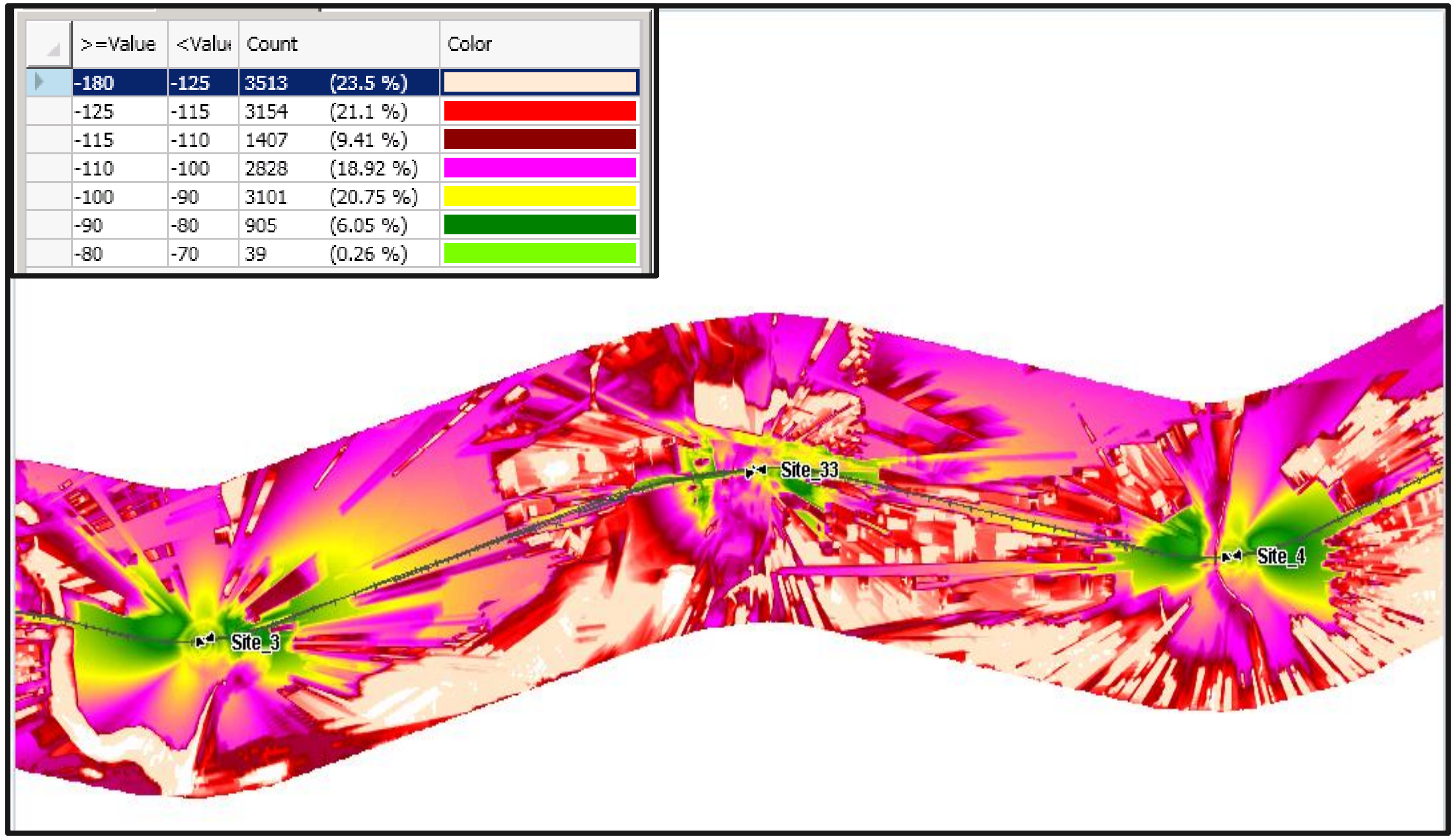


>=Value	<Valu	Count		Color
-180	-125	3513	(23.5 %)	
-125	-115	3154	(21.1 %)	
-115	-110	1407	(9.41 %)	
-110	-100	2828	(18.92 %)	
-100	-90	3101	(20.75 %)	
-90	-80	905	(6.05 %)	
-80	-70	39	(0.26 %)	

Inputs Planning Tool for selected scenario

- Rolle-Villeneuve 72km
- Green Field Planning
- 1900 MHz TDD Band (50:50)
- 10 MHz bandwidth (1900–1910)
- 22m Antenna height
- EIRP (Max TX PWR + Ag) = 40dBm
- 50% downlink loading
- 2dB uplink interference margin
- 98% Coverage Probability Factor
- SS-RSRP Threshold -124 dBm
- UL Throughput Threshold 5Mbps
- Resulting Intercell Distance ~2.2km

Planet Mentum Validation
RSRP Coverage Example



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-100	-90	3101	(20.75 %)	
-90	-80	905	(6.05 %)	
-80	-70	39	(0.26 %)	

Conclusion

- Spacing between sites should not be assumed as a general network planning rule in Switzerland, especially on selected track Rolle-Villeneuve due to different environments such as rural, sub-urban, urban, tunnels and mountainous.

- In the detailed document are presented the RSRP, SINR, DL&UL Average Throughputs Simulations which corresponds to theoretical predictions, but are very **dependent on the end selected scenario.**

SBB CFF FFS

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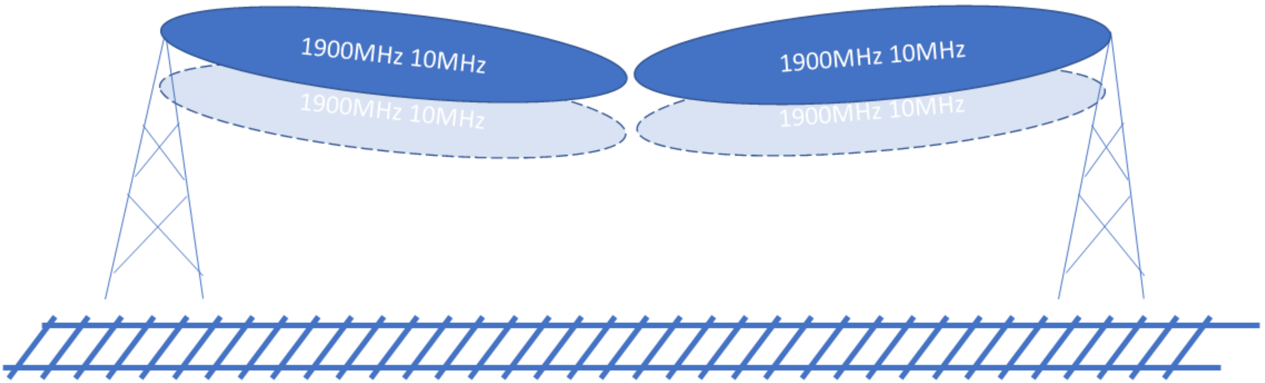
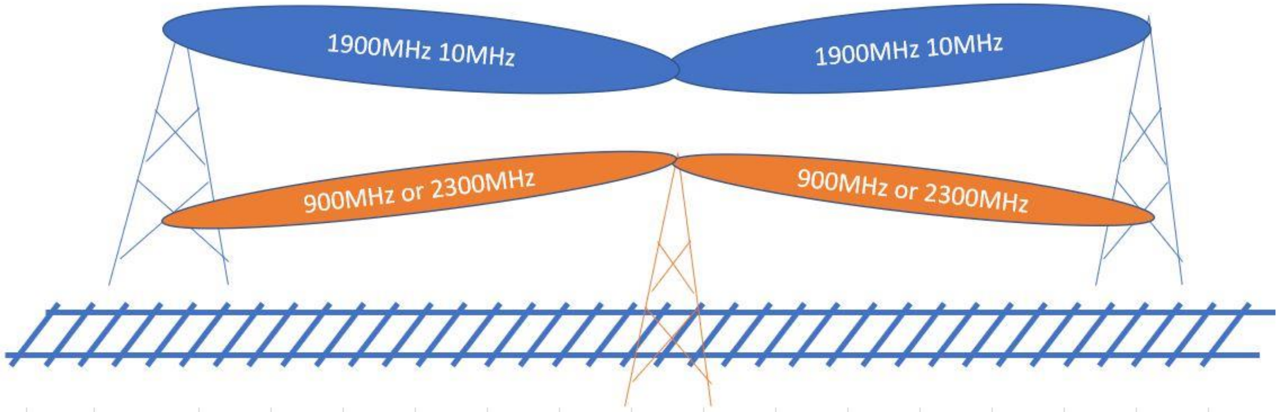
Radio Redundancy concepts



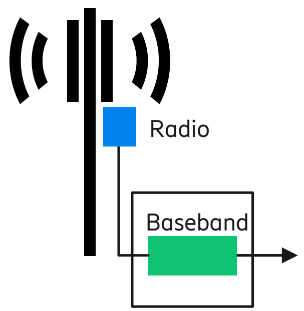


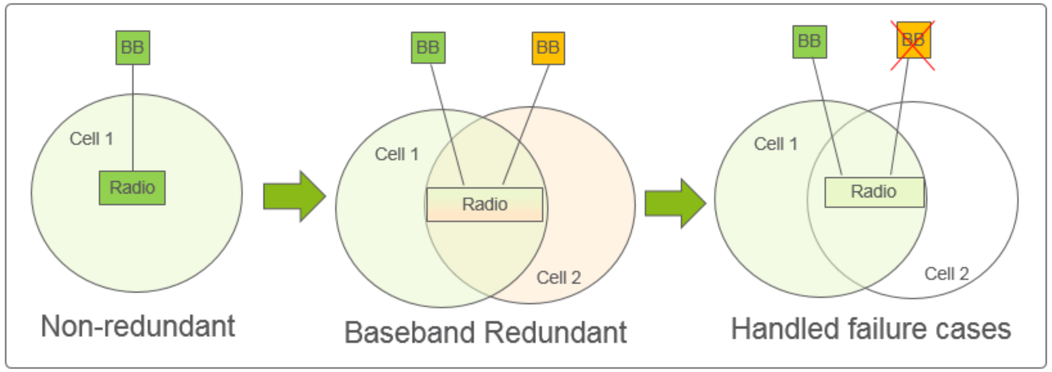
- The redundant layer is in Standby mode and is prepared to go ON AIR on demand.
- This scenario is independent from any other spectrum asset.
- Redundancy cannot be assured if one site fails (e.g. tower collapse).

- This scenario mitigates with one offset site broadcasting cells on different band when the spectrum would be become available.
- The additional redundant bandwidth can be used as a carrier aggregation layer to increase the performance in normal operation.

Baseband Redundancy Concept

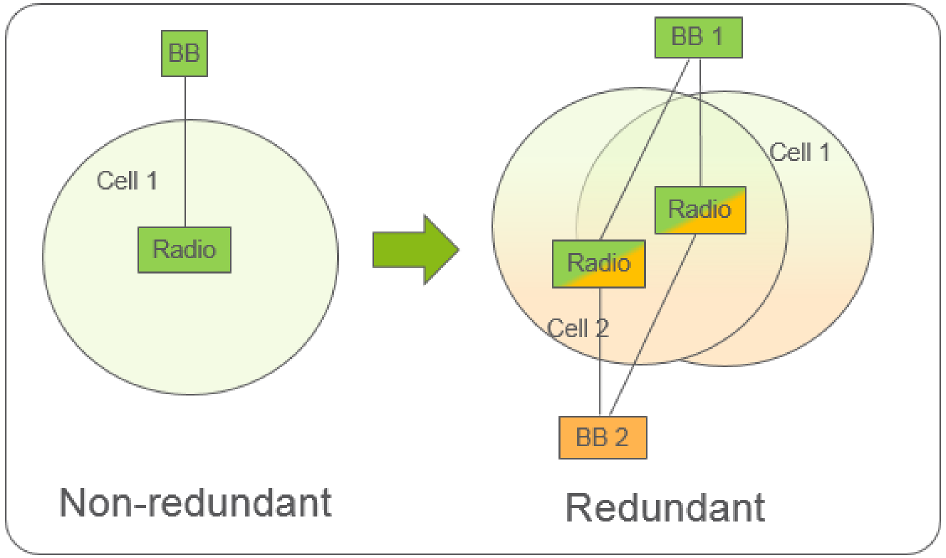
- In order to achieve baseband hardware redundancy two inter-frequency overlapped cells on two basebands covering the same area needs to be configured.
- Two frequency bands are required.
- Dual Connectivity (or Carrier Aggregation) can be used to split traffic over two cells. In case of BaseBand (BB) or Radio Unit failure system works with reduced bandwidth
- Due to bandwidth split over two overlapping cells, load sharing between the cells will be required to minimize performance degradation.

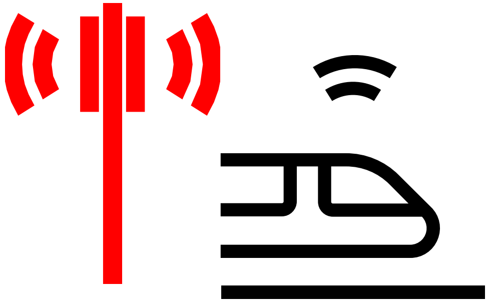




Baseband and Radio Unit Redundancy concept

- Radio Unit redundancy can be obtained with Combined cell option where two radio units are configured as one combined cell, if one radio fails, the cell is still enabled with one sector-carrier to provide service.
- With Combined Cell, several radio units operating different sectors can be part of the same cell (same PCI).
- By combining BB and RU redundancy full redundancy can be achieved i.e. each combined cell is severed by 2 radio units with mixed mode radio capability.
- If either radio unit fails, the two cells are still enabled with another radio; if any Baseband unit fails, one cell is lost while the remaining cell will still have combined cell functionality with two radios.





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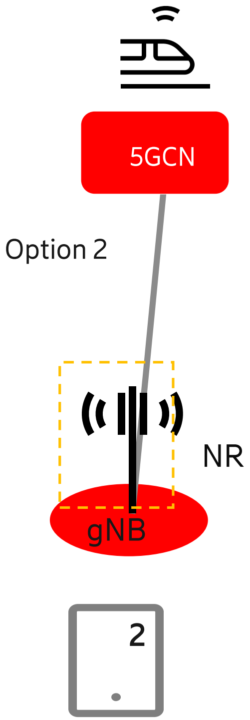
SBB Network Scenarios

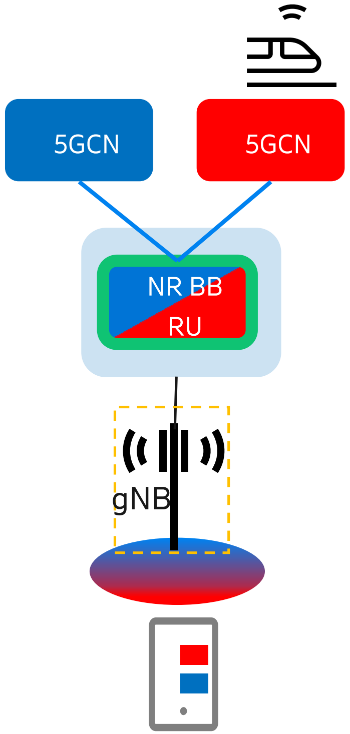
Sharing/Slicing options have an operator dependency. Cooperation/agreement is needed to secure the critical communication requirements in terms of availability and reliability.

Own SBB NW



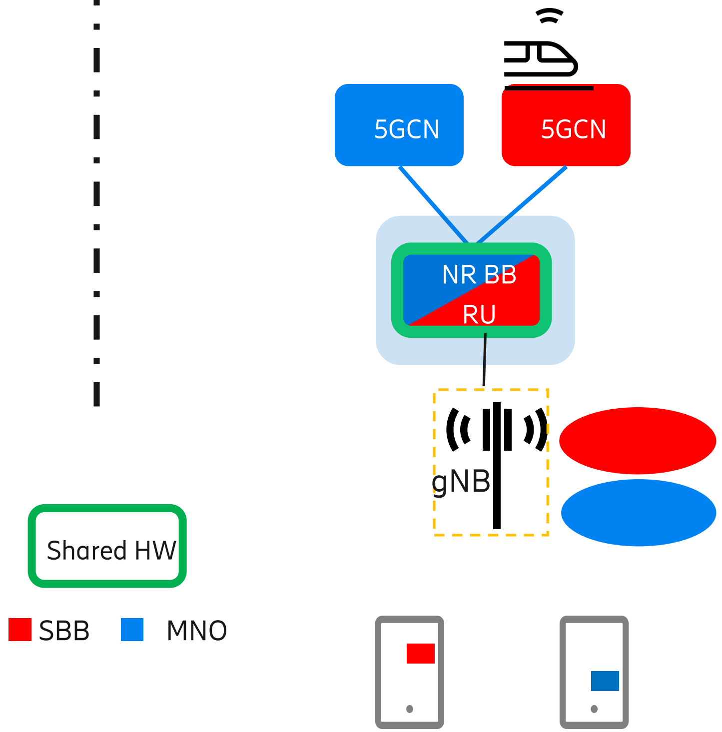
- SBB own Spectrum

Multi Operator Core Network (MOCN)



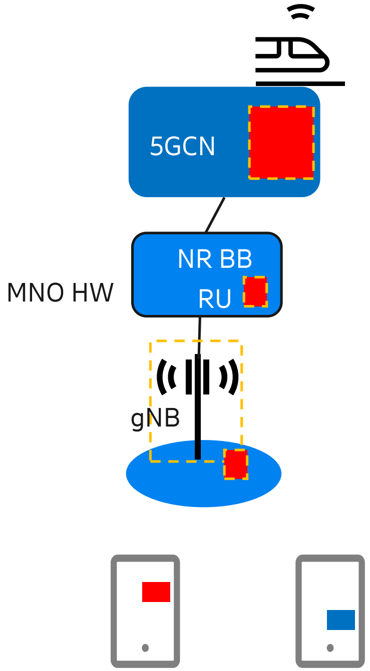
- Shared/combined Spectrum of SBB & MNO
- Separate Core Networks
- Optional common radio hardware

Multi Operator RAN (MORAN)



- SBB own spectrum
- Separate Core Networks
- Common radio hardware
- Mainly CAPEX savings

MNO (End to End Slicing)



- MNO Spectrum
- Service access through MNO slice

Wrap-Up

Coverage Conclusions for the potential railway spectrum

- 1900MHz/10MHz is a **viable solution for critical rail communications***
- **3 km intercell distance** can be achieved for a **3 Mbps uplink cell edge bitrate**
- **Multi array antennas** like 4T4R/8T8R and **advanced features** are options to **increase the uplink performance**.
- Using 5G instead of 4G slightly increases the throughput.
- By increasing the mast height from 16m to 22m the inter cell distance can be increase by approx. 16% by keeping same cell edge throughput.
- A different TDD pattern (20:80) can be used to increase uplink throughput and coverage:
  - At the expense of downlink throughput

* Final service level requirements for railway communications are still to be confirmed.