Developing & Maintaining the World's Largest* CP Model Using MiniZinc

Presented by Olle Virding, Danyal Mirza

Content

- Quick background on Ericsson and RAN networks
- Using combinatorial optimization in product configuration
- Developing, executing & maintaining very large CP models

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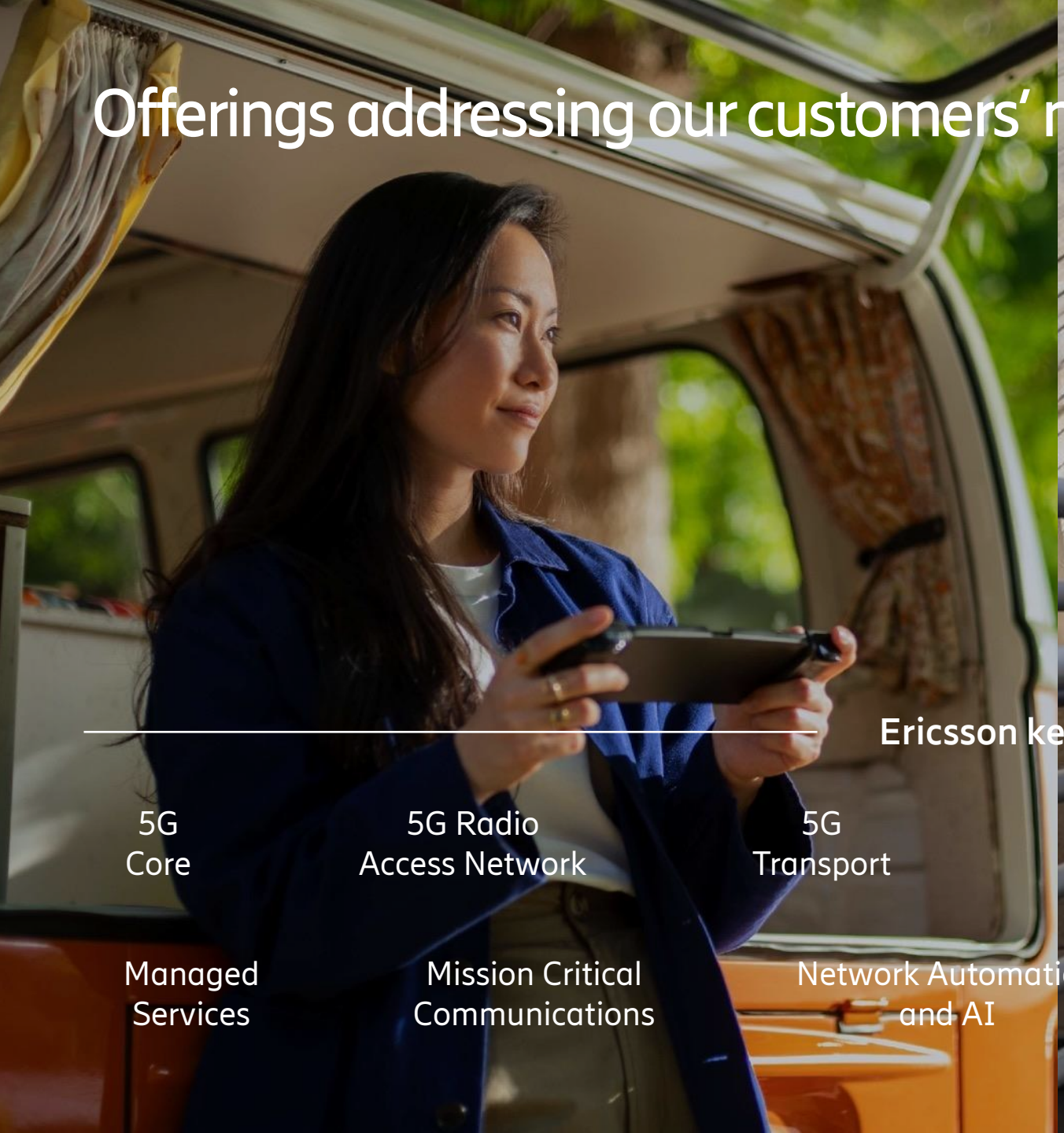
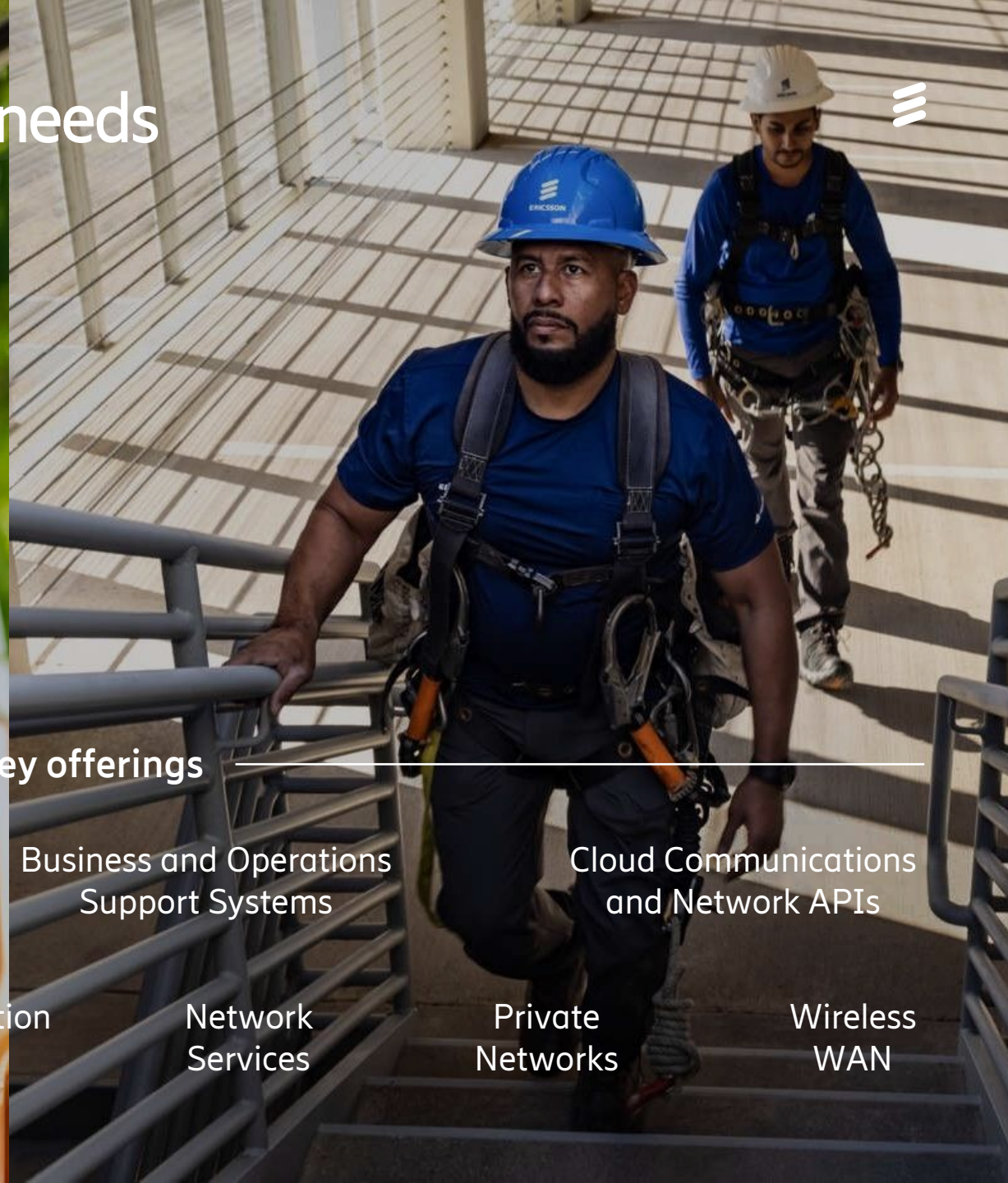
Offerings addressing our customers' needs

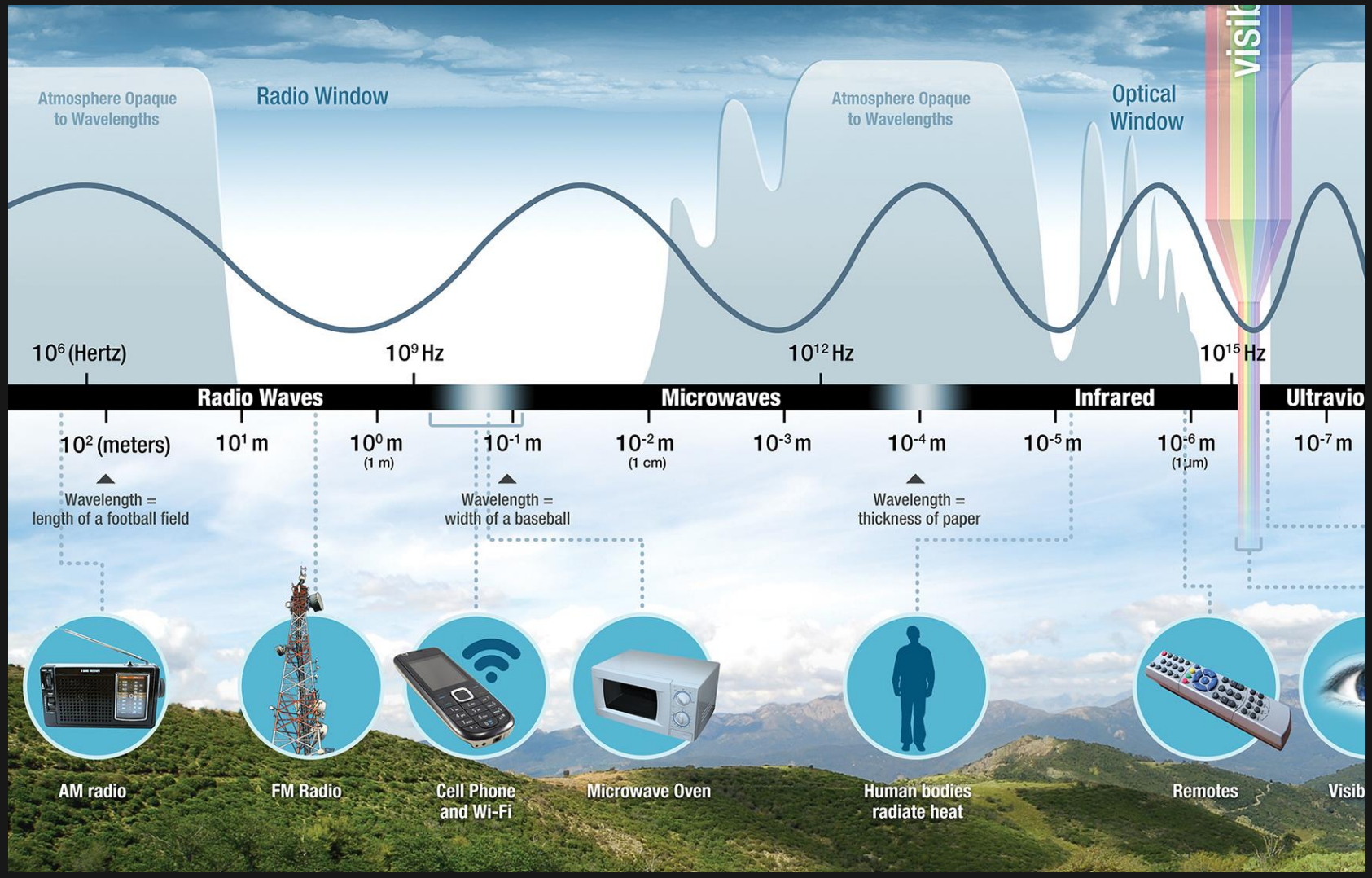




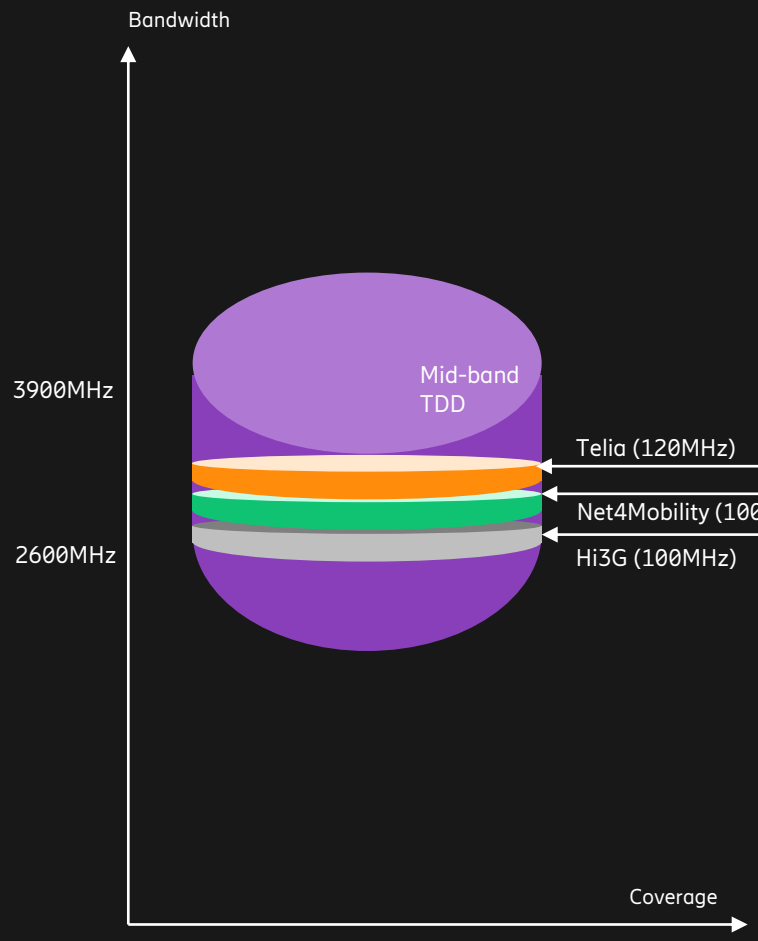
Ericsson key offerings

- 5G Core
- 5G Radio Access Network
- 5G Transport
- Business and Operations Support Systems
- Cloud Communications and Network APIs
- Managed Services
- Mission Critical Communications
- Network Automation and AI
- Network Services
- Private Networks
- Wireless WAN

Electromagnetic spectrum



Spectrum allocation



Telia (120MHz)

Net4Mobility (100MHz)

Hi3G (100MHz)

5G & Beyond | RAN | Access | News

Sweden completes spectrum auction in one day

By **Annie Turner** - 22 September 2023

Share

Licences were up for grabs in the 900MHz, 2.1GHz and 2.6GHz frequency ranges

Sweden's Post and Telecom Authority (PTS) announced the conclusion of its latest spectrum auction which kicked off on Wednesday.

Nordic telecom companies Tele2, Telenor Sweden and Telia Co have all acquired licences in the latest Swedish spectrum auction. They collectively invested SEK3.03 billion (€254.68 million) for spectrum allocations in the 900MHz, 2.1GHz and 2.6GHz auction.

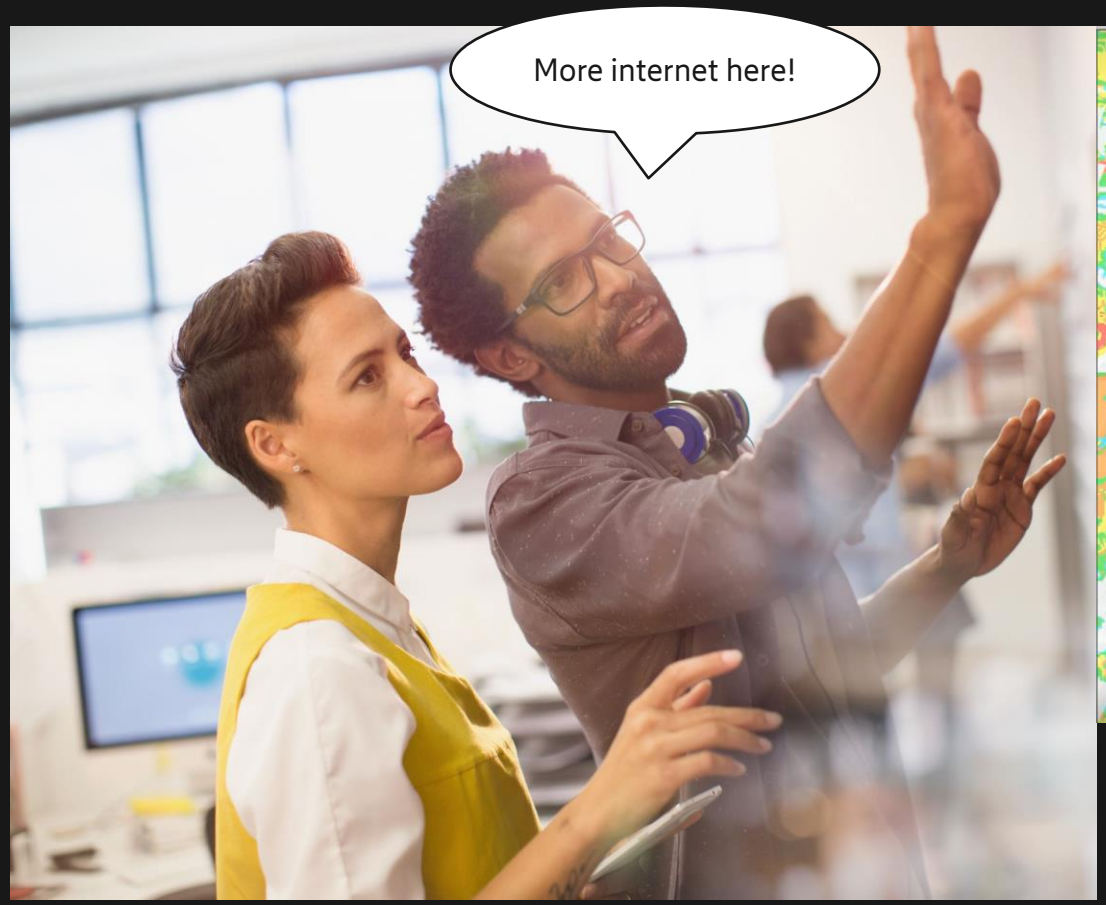
Who got what

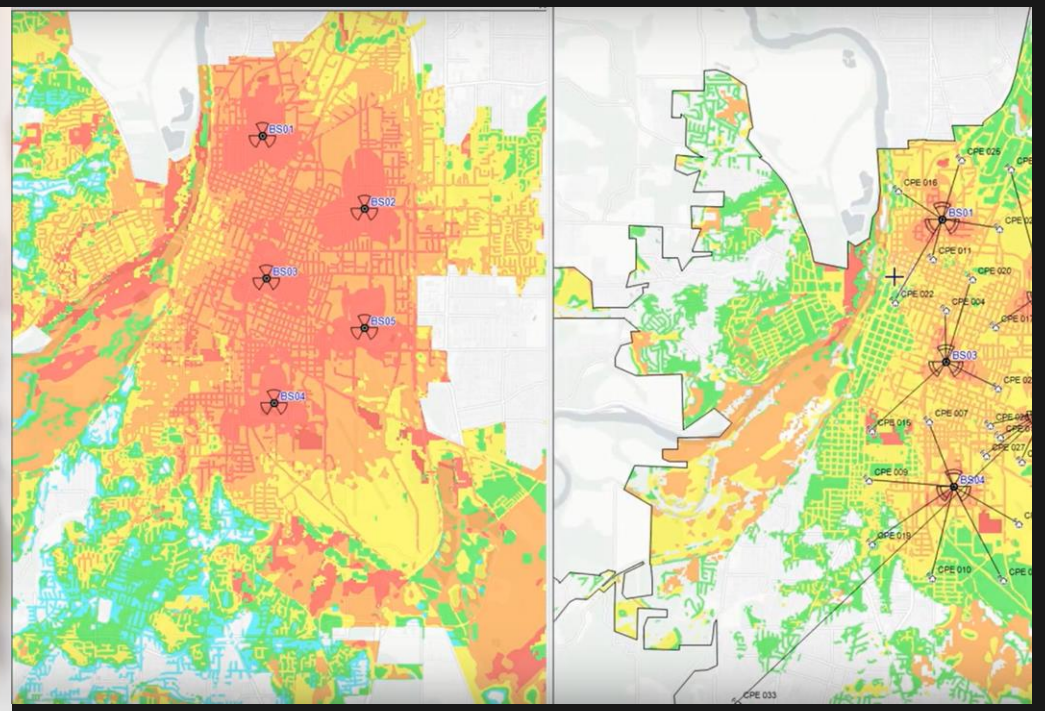
In a statement, PTS noted all 320 MHz at 3.5 GHz was assigned. Full allocations are as follows:

- Telia secured 120MHz (3500-3620 MHz) for SEK760.25 million SEK (€75 million)
- Net4Mobility (the joint venture between Tele2 and Telenor Sweden) won 100MHz (3620-3720MHz) for SEK665.5 million (€65 million)
- Hi3G secured 100MHz (3400-3500 MHz) at SEK491.25 million (€48 million)
- Teracom Group, which took over Net1 in 2019, won all the 80MHz on offer in the 2.3 GHz band for a total of SEK400 million (€40 million)

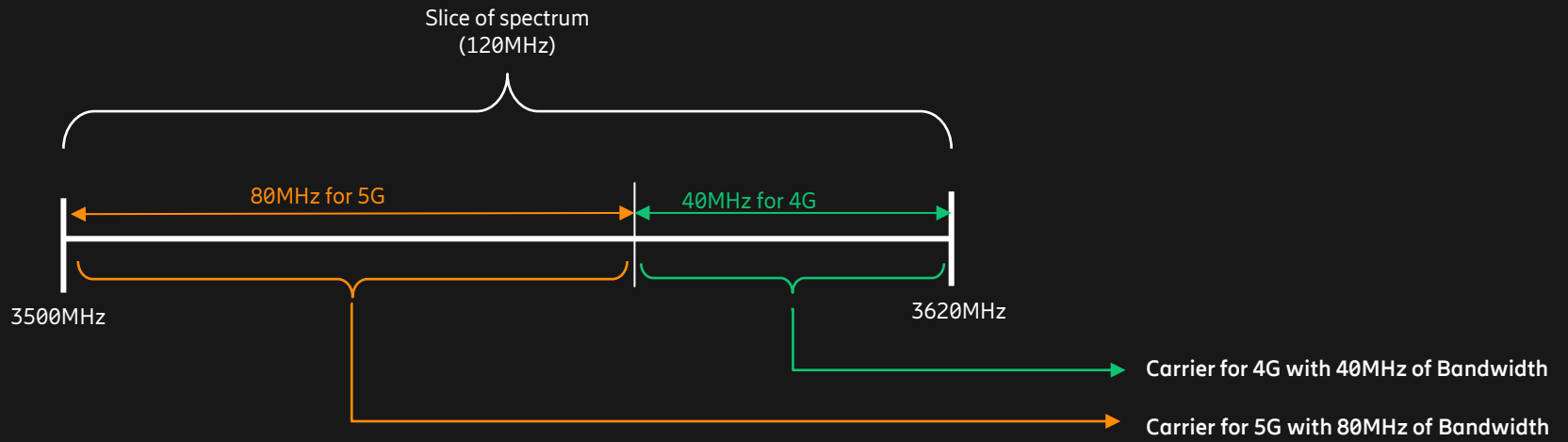
The four 3.5 GHz licences will be valid for a period of 25 years, from 20 January, 2021 to 31 December, 2045.

The network plan





Output of Planning Activity

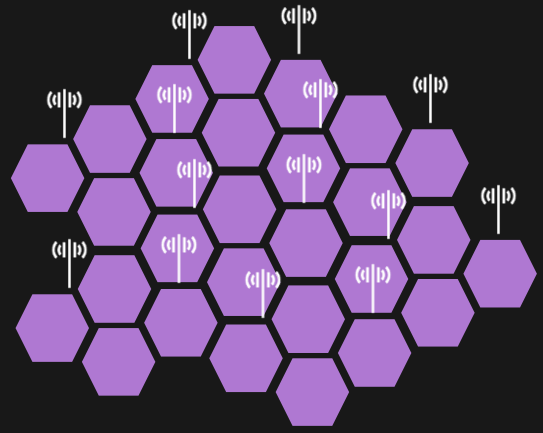


Option-1
- Full 120MHz for LTE (4G)

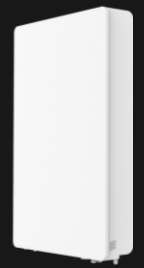
Option-2
- Full 120MHz for NR (5G)

Option-3
- Mix of 4G & 5G
  - 60MHz for each
  - 40MHz for LTE & 80MHz for NR
  - And so on.....

Number of Sites



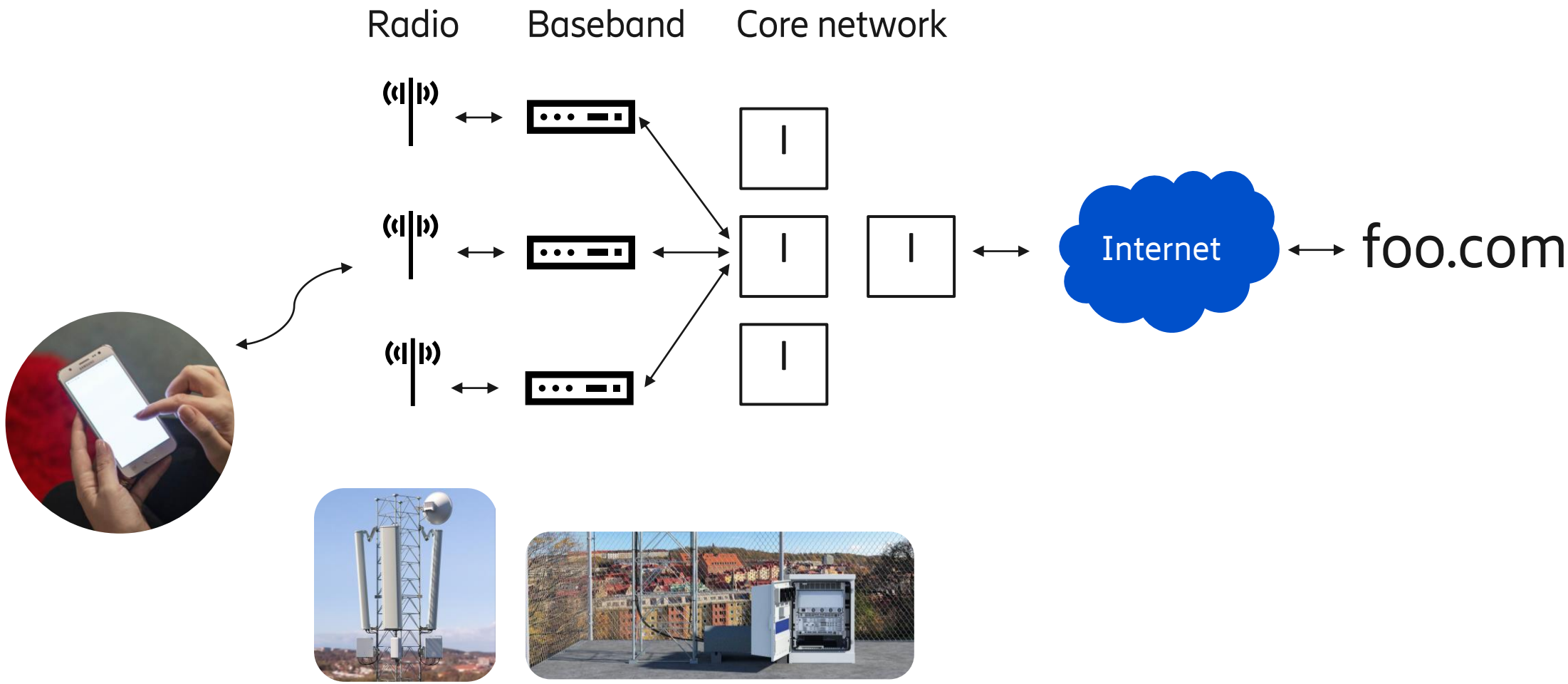
Radio ?? (3500-3700MHz)



Radio ?? (3410-3800MHz)

Radio ?? (3450-3800MHz)

Radio Access Network (RAN) Overview



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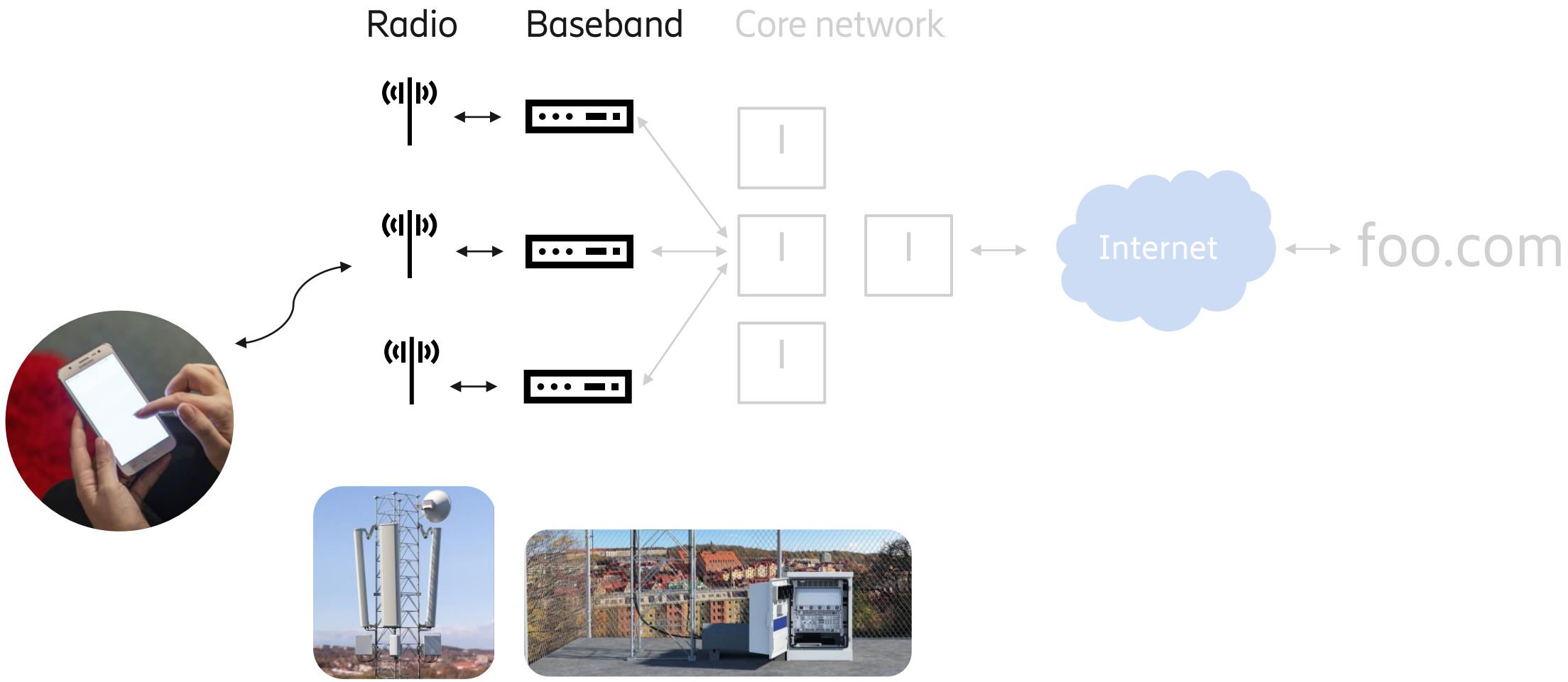
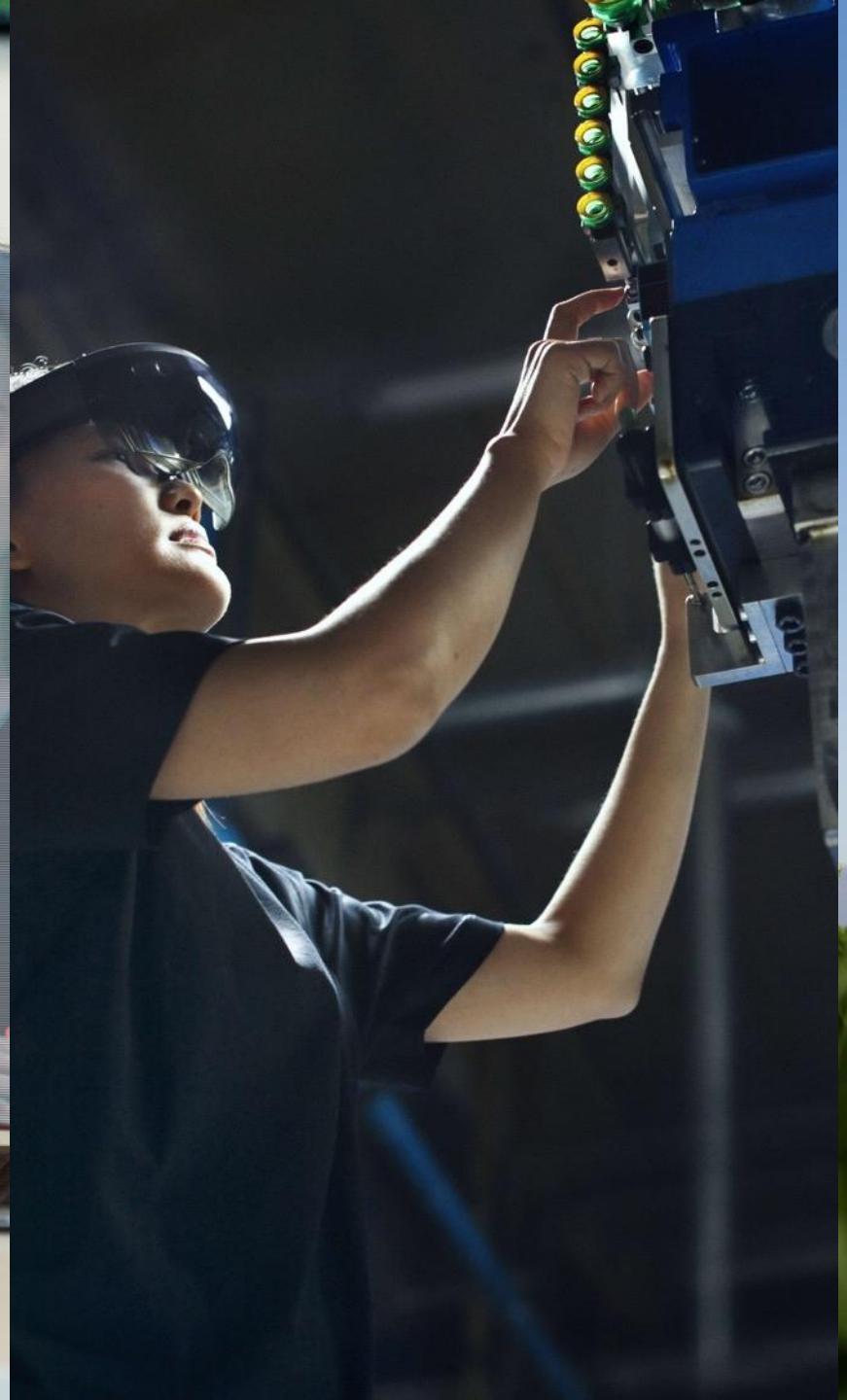
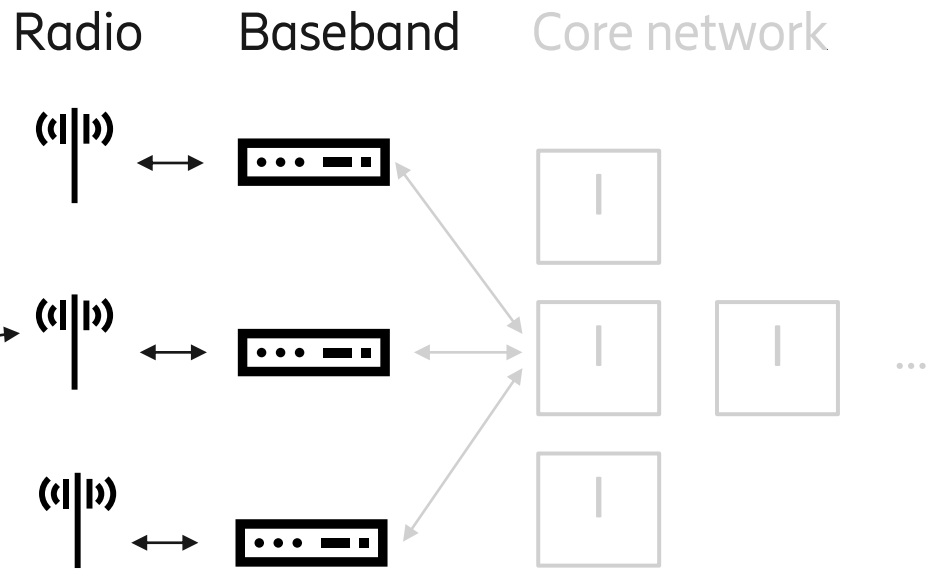




Product Configuration @ Ericsson

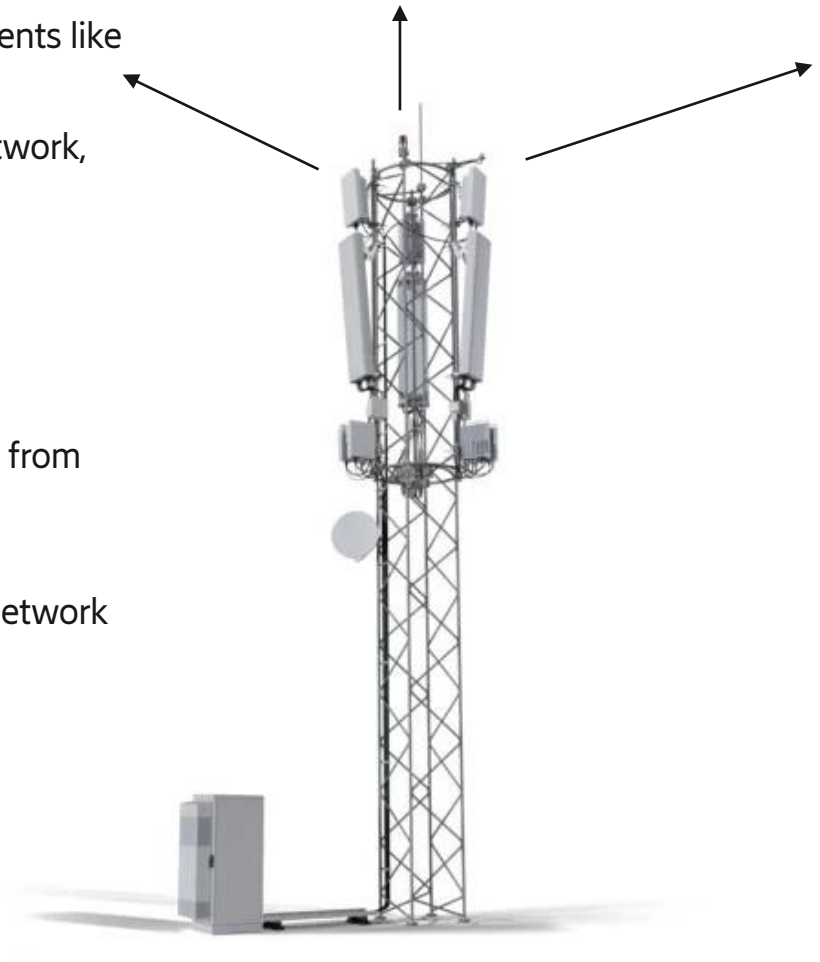
- Help sales & support
- Configuration engines customize products to meet needs – like buying a couch
- When configured you get a list of all components that needs to be bought
  - Includes the non-obvious parts like screws etc

What are we configuring?



Product configuration – The site

- **Antenna System**: responsible for transmitting and receiving radio signals. It includes components like antennas, cables, and connectors.
- **Carrier:** range of frequencies allocated for transmitting and receiving signals on a wireless network, typically defined by its center frequency and bandwidth. (ephemeral)
- **RF Port:** interface that connects radio to antennas, split RX⬇/TX⬆ traffic.
- **Radio:** wireless communication component that transmits and receives radio signals.
- **CPRI Ports:** interface that connects radio to baseband, ⬇⬆ traffic.
- **Baseband:** network that handles the lower frequency signals, after they have been converted from radio frequencies (RF) by an antenna and receiver. It performs tasks such as switching, traffic management, timing, baseband processing, and radio interfacing.
- **RAN Compute**: This refers to the computing resources required to support the Radio Access Network (RAN), such as baseband units or virtualized RAN functions.
- **Enclosure**: physical housing that protects the radio equipment
- **Power Supply**: provides the electrical power to operate the radio solution
- …



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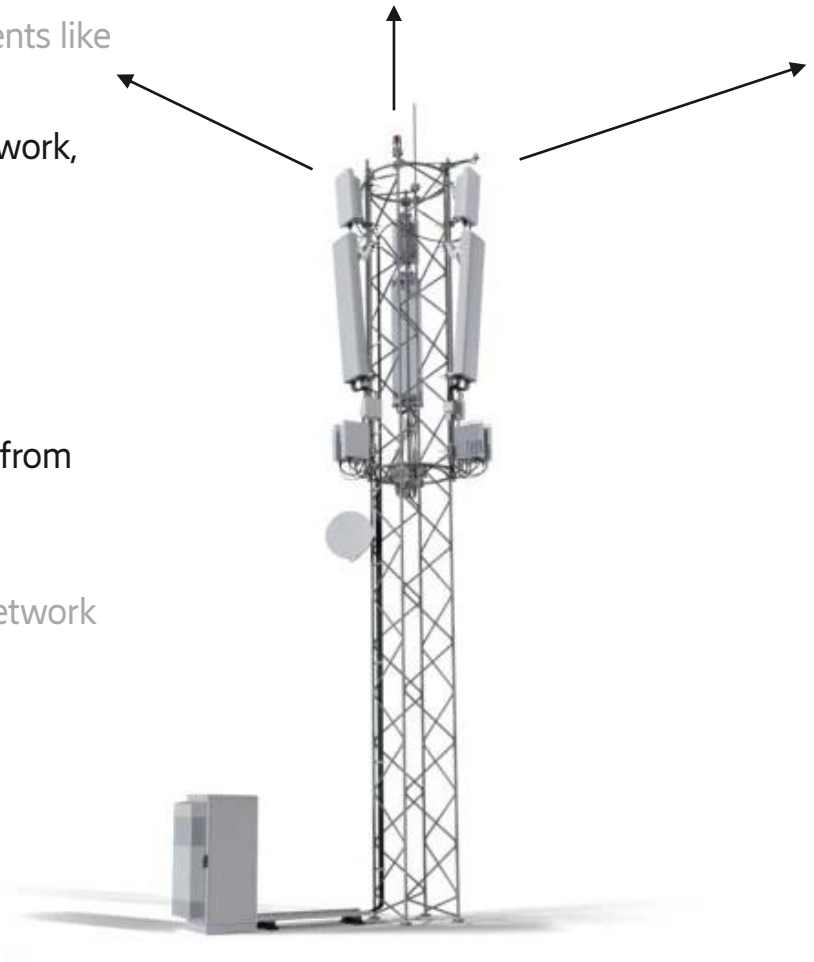
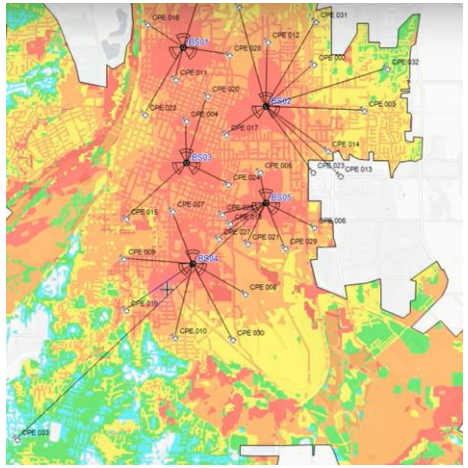


Radio Solution– The requirements

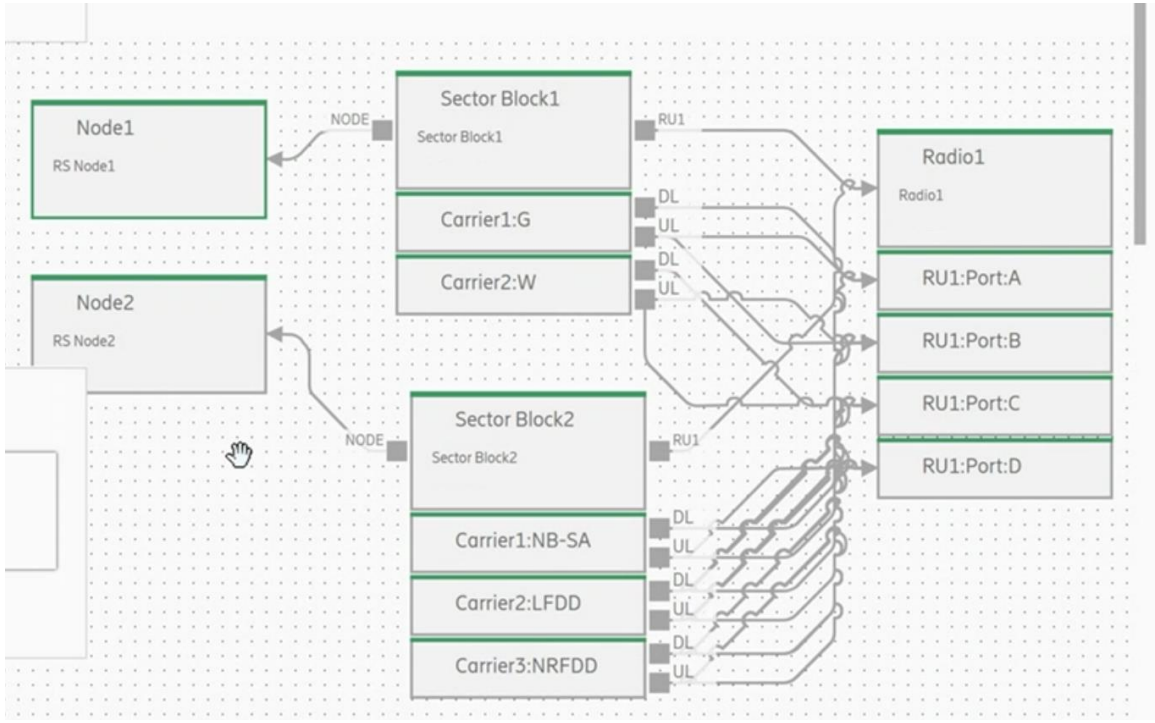
- Site 1
  - GSM carrier
  - 3G carrier
  - 2 x 5G carrier
- Site 2
  - 2 x 4G carrier
  - 5G carrier
- Site 3
  - GSM carrier
  - LTE carrier
- …



Product configuration – Radio solution

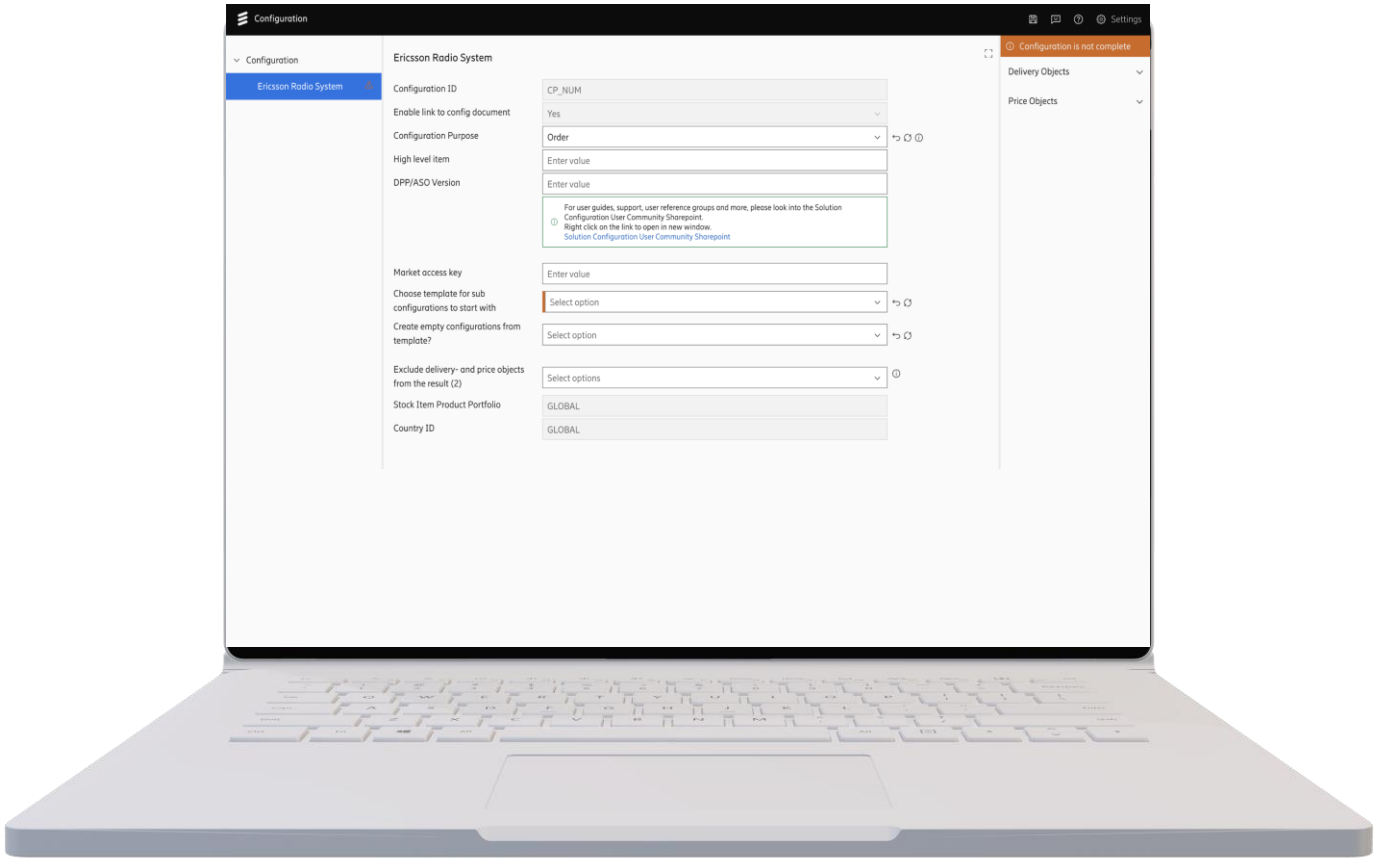
Resource allocation - a combinatorial optimization problem

- Radio Solution:
  - Carriers ⇆ Radios
- Solution:
  - ~50 table constraints
  - Bin-packing (e.g. connecting cables)
  - Linear constraints (capacities)



Given a set C of carriers, select a set R of radio units and map every carrier $c \in C$ to a radio $r \in R$ such that r meets all demands of c mapped to r and the capacities of r are not exceeded.

Demo

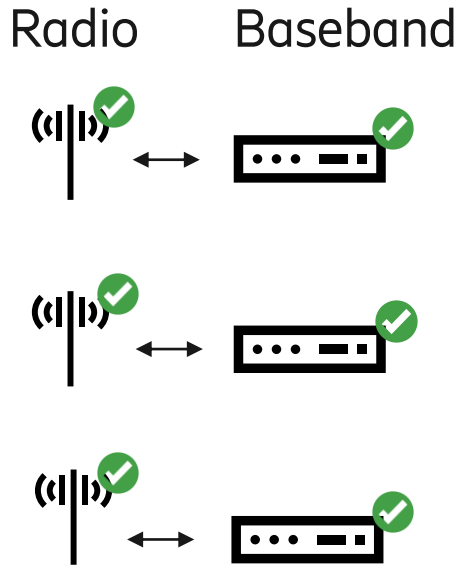

Configuration
Settings
Configuration
Ericsson Radio System
Ericsson Radio System
Configuration ID
CP_NUM
Enable link to config document
Yes
Configuration Purpose
Order
High level item
Enter value
DPP/ASO Version
Enter value
For user guides, support, user reference groups and more, please look into the Solution Configuration User Community Sharepoint.
Right click on the link to open in new window.
Solution Configuration User Community Sharepoint
Market access key
Enter value
Choose template for sub configurations to start with
Select option
Create empty configurations from template?
Select option
Exclude delivery- and price objects from the result (2)
Select options
Stock Item Product Portfolio
GLOBAL
Country ID
GLOBAL
Configuration is not complete
Delivery Objects
Price Objects

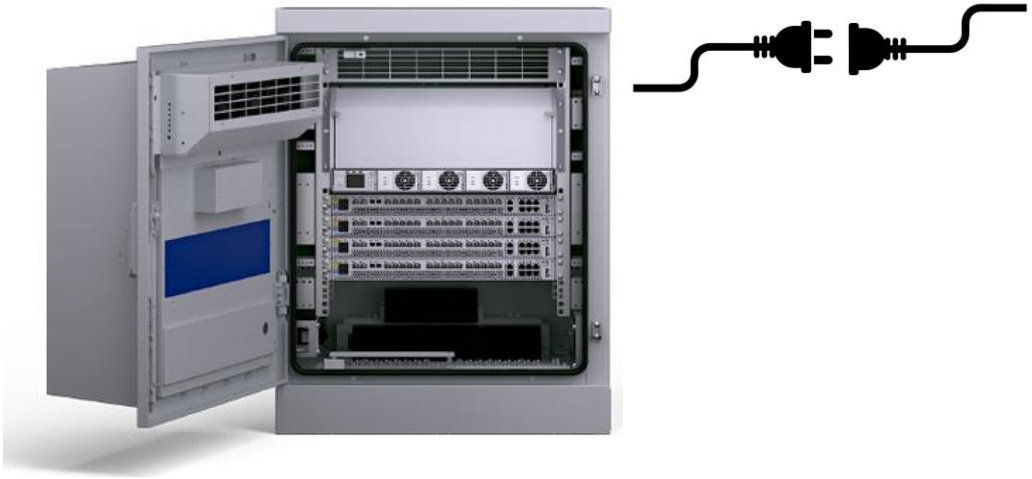
Product configuration – Which is best?

- Minimize radio equipment
  - number of radios
  - …
- Optimize
  - Output power
  - Weight
  - Size
  - Other customer desires?
- The objective function is subjective!

Product configuration – Model Portfolio

- Carrier to Radio
- Carrier to Baseband
- Hardware Activation Codes
- Rail Allocation





Product configuration – HWAC

Product configuration – HWAC

- RTX 5090
  - 30.000 kr
  - 32 GB VRAM

32 GB

Included package

4 GB Hardware Upgrade Package A

4 GB Hardware Upgrade Package B

8 GB Hardware Upgrade Package C

16 GB

Radio Solution – A Large CP Model

The Radio Solution Model

- 114 Constraints
  - 89 Core Constraints
  - 25 Improving Constraints (Symmetry breaking/Redundant)
  - 50 Table Constraints
- 110 Decision Variables
- 96 Data tables

Data Tables

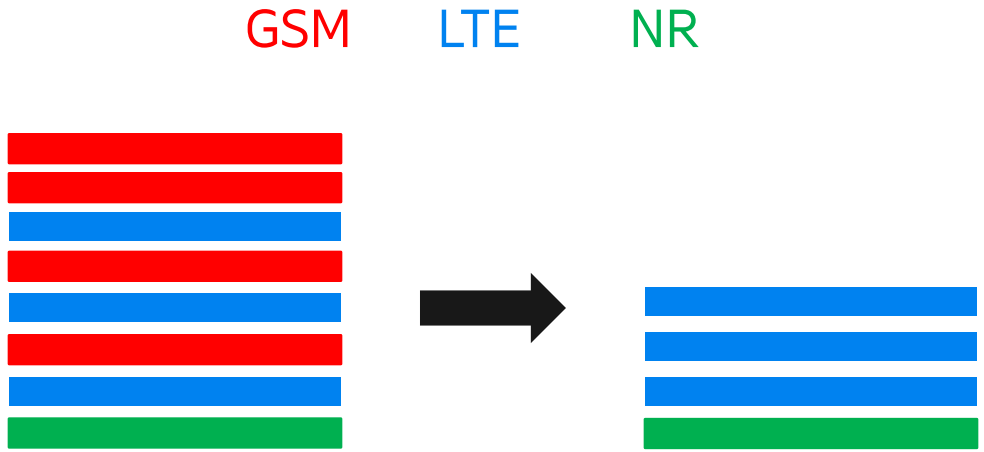
```
 1 ROWS   TABLE
 2 20936  tab1.dzn
 3 16667  tab2.dzn
 4 10914  tab3.dzn
 5 7465   tab4.dzn
 6 6460   tab5.dzn
 7 3783   tab6.dzn
 8 2974   tab7.dzn
 9 2767   tab8.dzn
10 2406   tab9.dzn
11 1724   tab10.dzn
```

- A lot of data, large tables
  - Largest ~21k rows
- Array of records
  - [(A: a1, B: b1, C: c1),
    (A: a2, B: b2, C: c2),
    (A: a3, B: b3, C: c3)]
  - Explicit declaration
  - No accidental column mismatch

```
array[int] of record( RfPortPatternOrNull: rf_port_pattern
                    , int: port_index
                    , bool: tx
                    , bool: rx ): RppPortTxRxTab;
%%%
```

Pre-filtering

- Lots of data, lots of radios to choose from
  - Based on the instance, filter certain radios
- Create sub tables
  - "If there is no GSM carrier for this instance, why have data for it in the tables"
- Drastically decreases solve time

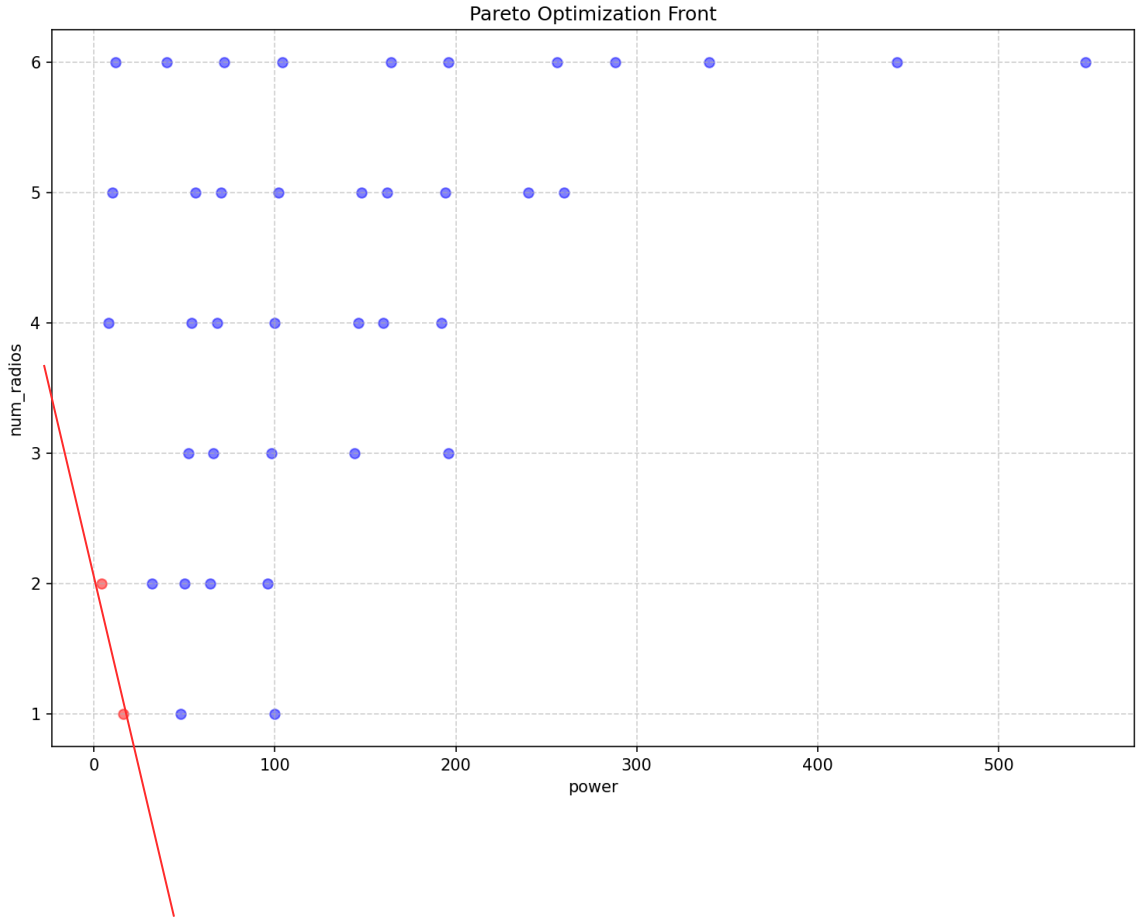


Lexicographic Optimization

```
PriorityOfRadioObjDefault = [1,2,4,0,0,3];
PriorityOfRadioObjVolume =  [0,0,0,1,0,0];
PriorityOfRadioObjWeight =  [0,0,0,0,1,0];
```

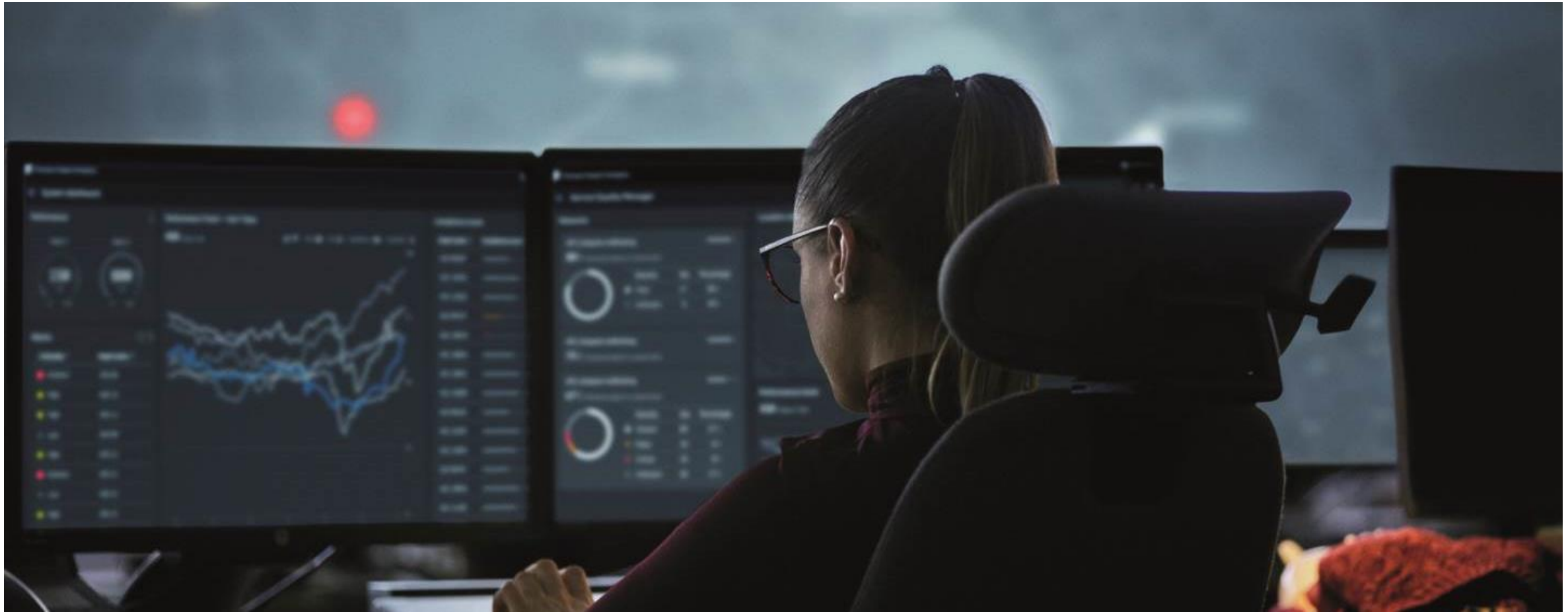
- Lexicographic
  - First optimize on f_1 then on f_2 etc
  - Keep f_1 as low as possible, f_2 should also be minimized but f_1 should still be at its lowest point
- Default - Multi-objective, minimize:
  - Number of Radios
  - Number of Ports
  - Number of frequency ranges
  - Power

Multiple Solutions

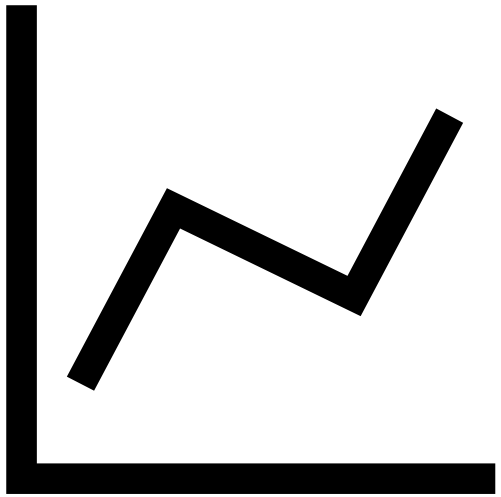


- Run with several times with different optimization scenarios
- Pareto optimization
  - Multi-objective
  - Gives all optimal solutions in respective to each objective

Maintaining our CP model



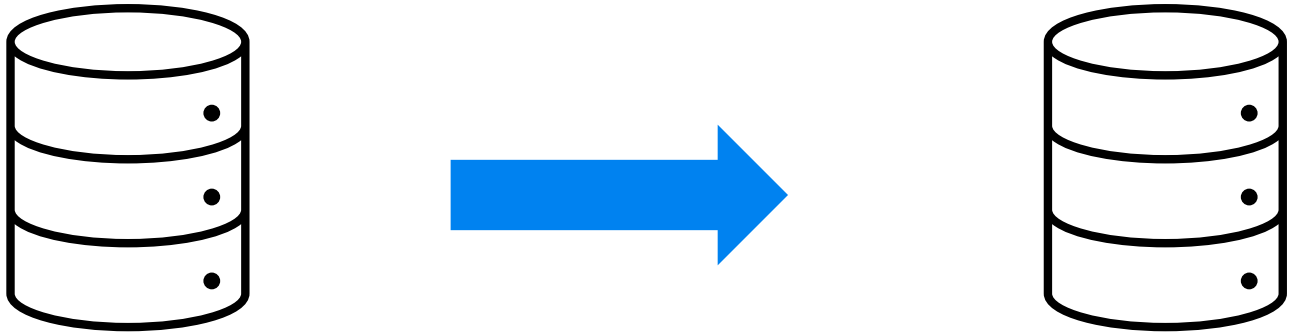
Ever increasing complexity
2x over the last 2 years



- +4K LoC *.py → +8K LoC *.py
- +4K LoC *.mzn → +8K LoC * .mzn
- +7K LoC *.rst → +10K LoC *.rst
- +60K LoC *.dzn → +120K LoC *.dzn
- 30 testcases → ~140 testcases

- New products
- New rules
- New language features

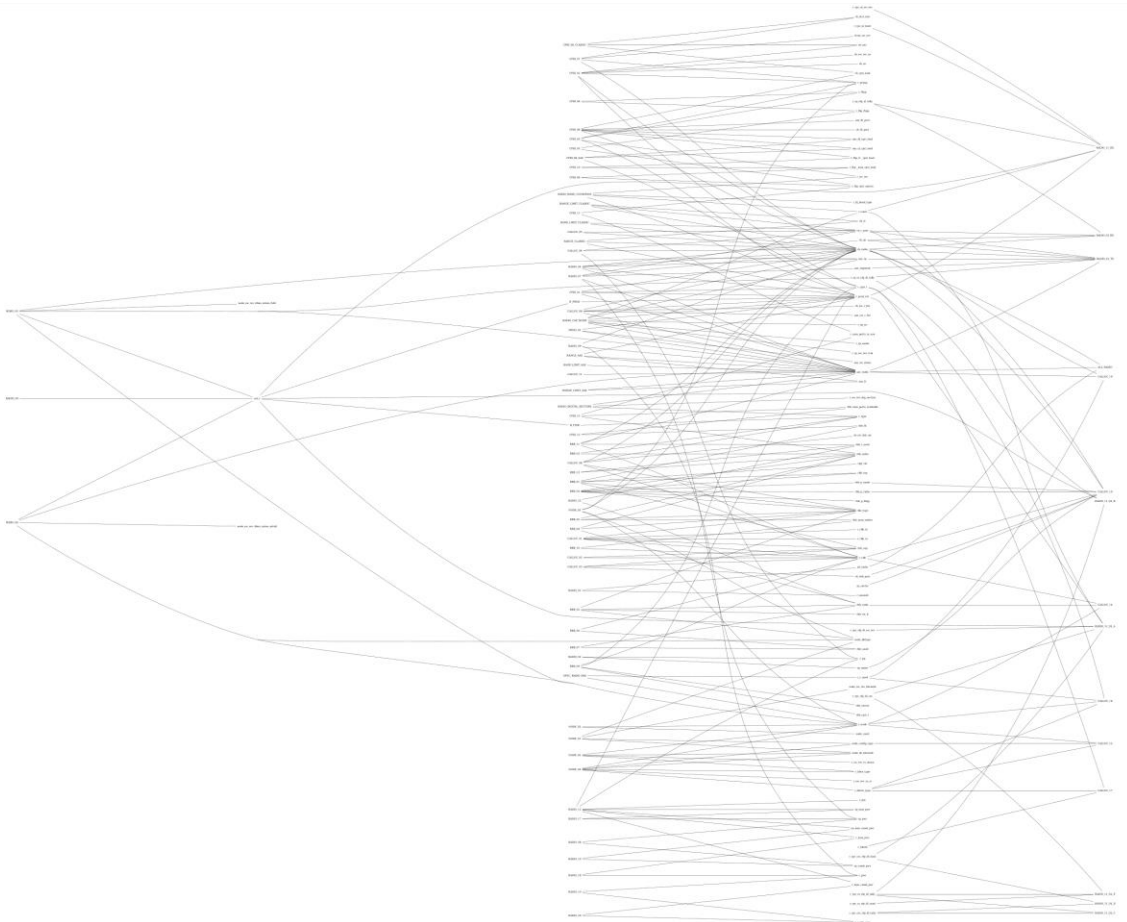
Living Data / Monthly Release



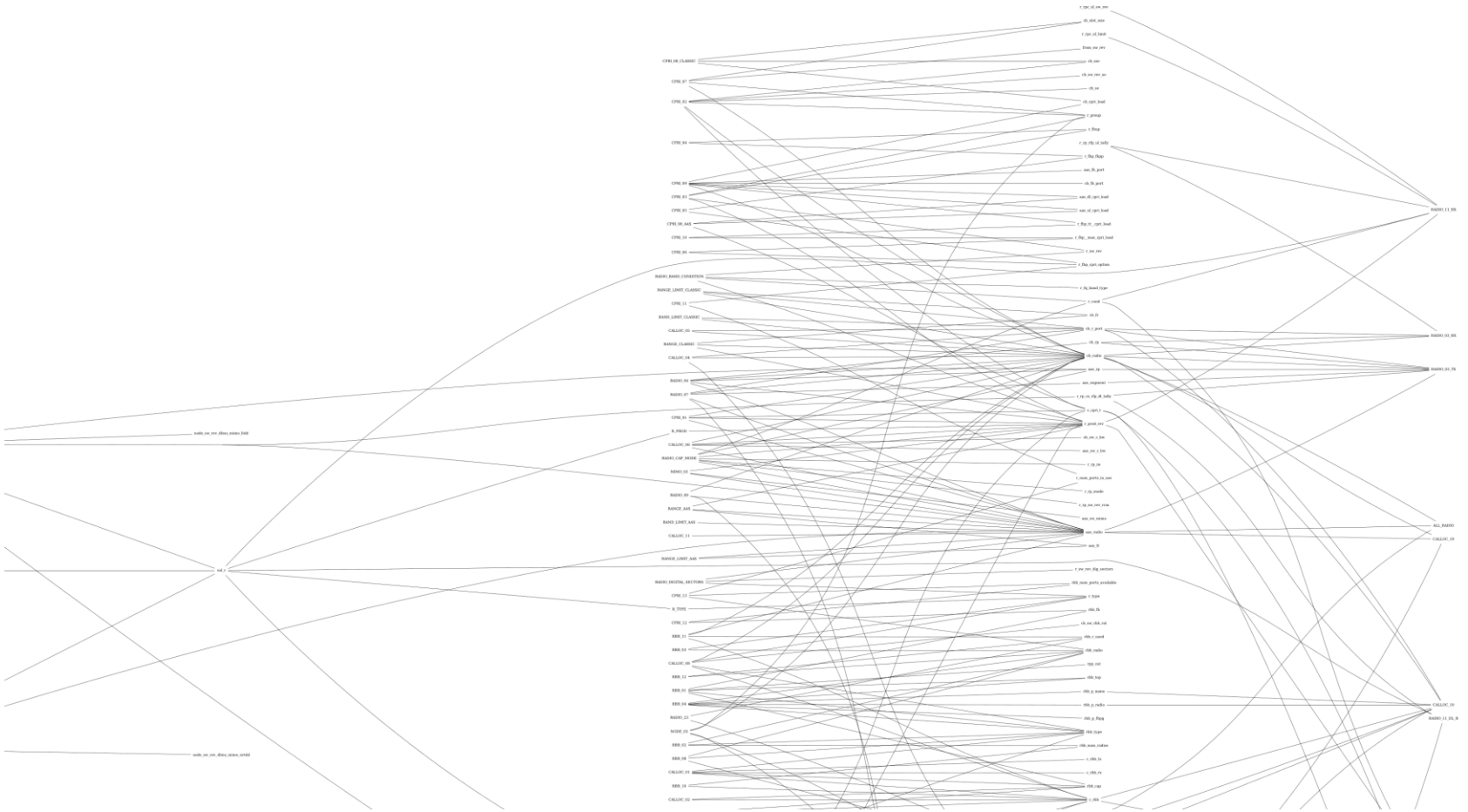
Living Data / Monthly Release

- New Radios/Baseband/Routers
  - New Hardware revision
  - New Software revision
- New or Reworks of Rules
  - New table
- EOS for Units

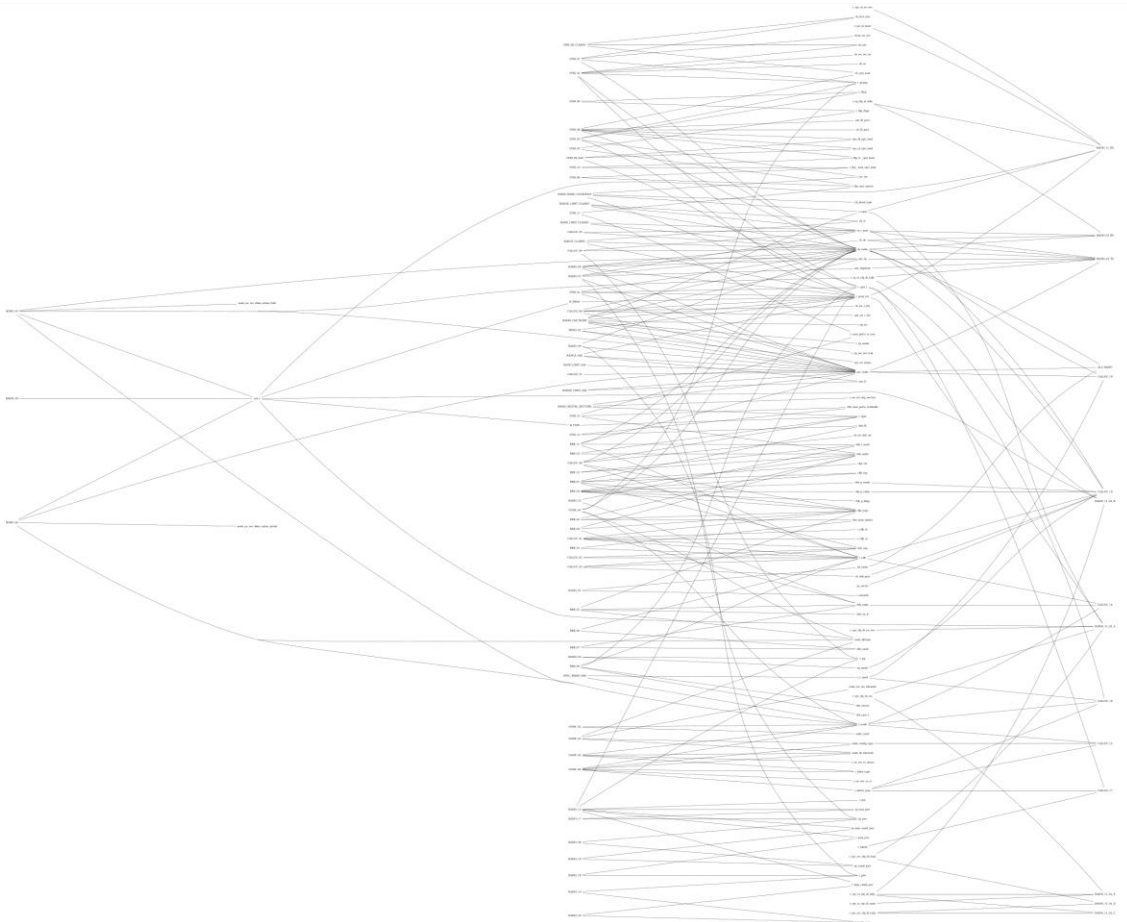
All constraints & decision variables



All constraints & decision variables

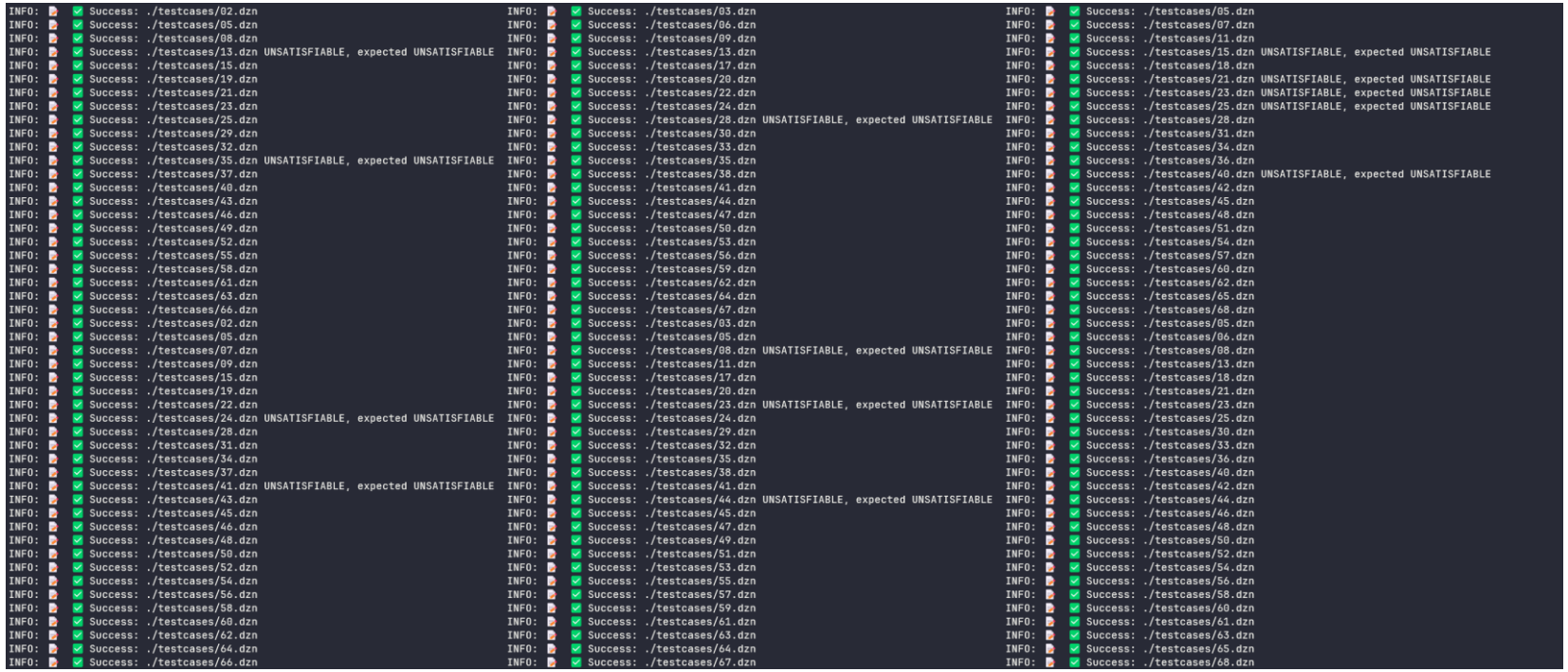


How do we deal with this complexity?



More test + integration

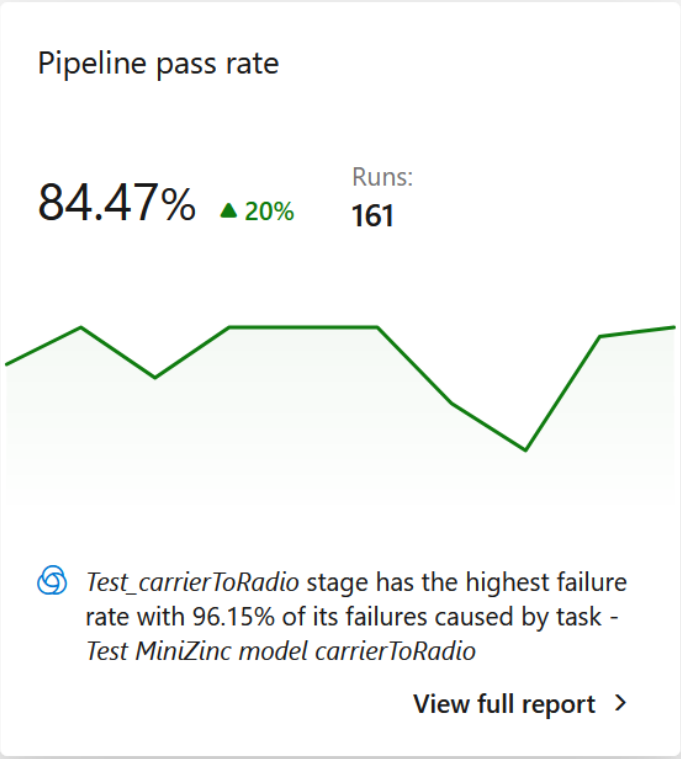
Better test coverage, less regressions & bugs 👏 👏 👏



- Testing both SAT/UNSAT
- New rules
  ➡️ new test
- New bug/regression
  ➡️ new test

Challenges – Testing

- Hard to test specific parts of the model
  - Need to test the whole model
  - Test using partial assignments
  - Test both for SAT/UNSAT
  - Indirect tests
- Rigorous testing
  - Automated testing (CI/CD/MLOPS)
  - Improving coverage (removing constraint should fail)
  - Large changes difficult (testcase might be symmetrical)



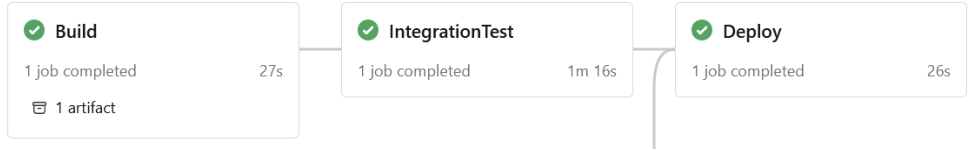
Exterminating bugs!

- Compiler errors
  - Stronger types (enums, records etc.)
- Consistency errors
  - Automatic test coverage (~120 testcases) + git bisect
  - Oracle model (SAP SSC)
- Interface errors
  - Strong contracts (types/SemVer)
  - Integration testing
- Solver bugs
  - Compare solvers
- Compiler bugs
  - Segfault/Strange behavior
    - Divide & conquer

```
.PHONY: test
test:
	MZN_ARGS="$(MZN_ARGS)" ../scripts/test-minizinc.sh $(TESTOPTS) $(MODEL) $(TESTCASES)
```

4.2.1

MAJOR *Minor* patch



Suspected presolver bug in fzn-cp-sat 9.10.4067 Bug Solver: CP-SAT Solver
#4392 · by matsc-at-sics-se was closed on Oct 4, 2024 v9.12

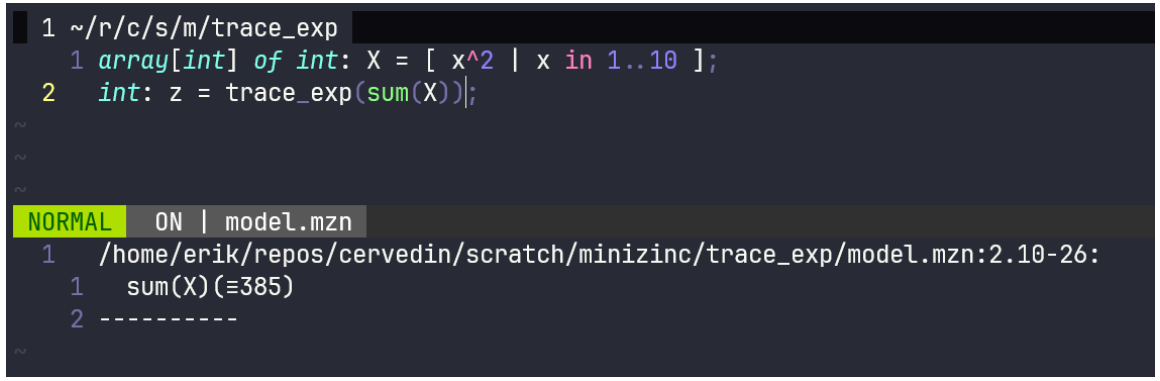
Concatenation of records sometimes gives strange results, depending on property names bug resolved
#892 · by CervEdin was closed on May 23

Accessing out-of-bounds elements in type array[int] of record(array[int] of ...) bug resolved
#954 · by dannem1337 was closed on Sep 25

Incorrect model inconsistency detected. Tuple in Array of Tuples bug resolved
#955 · ollevirding opened on Sep 29

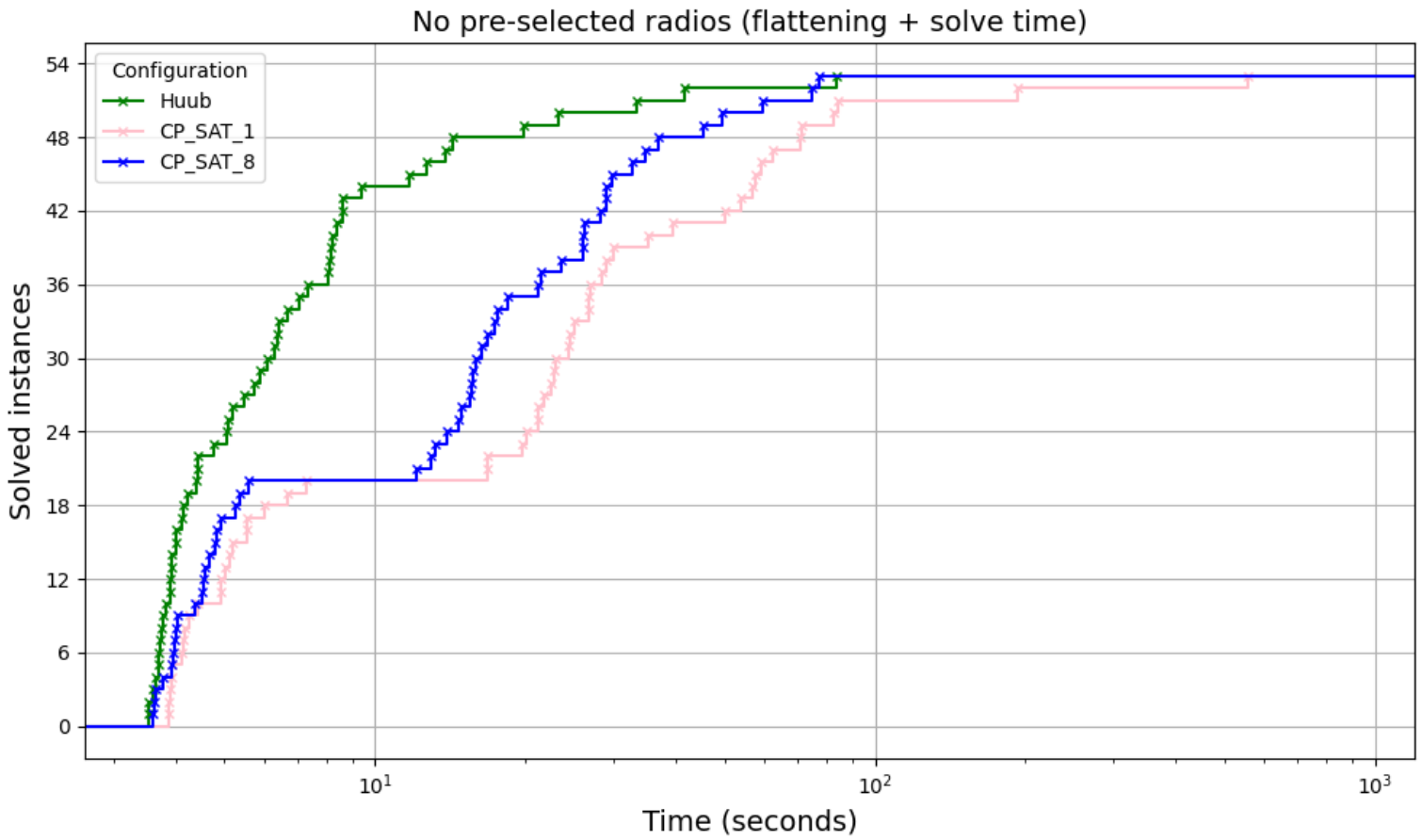
Challenges – Debugging

- Conditional debug output
- `trace_exp`
  - Prints an expression and value
- Black box
  - Poke the box and see what happens!
    - Manual assignments
    - Manually bisect constraints (delete/comment) until UNSAT becomes SAT



Improving performance

Experimenting with other solvers



Whats next?

- Unit type support in MiniZinc 3.0 *(length, volume, unit etc.)*
  - Type safety
  - Debugging
- New models
  - Facility placement
- Combining constraint programming with other fields
  - Reinforcement Learning
  - Large Language model
- Language Server Protocols

Conclusion

How to build a large CP model & live to tell the tale

- Test, test & test
- Make incremental changes
- Flexibility & reliability before performance
  - It's easier to make a **correct** program fast than a **fast** program correct.
- Have fun!

Q&A


Imagine Possible
ericsson.com/careers