GRANDMETRIC

NETWORK & WIRELESS... STAY CONNECTED.

Do we need **next G's?**

2nd Annual World 5G Summit, Barcelona, 10.10.2019

Marcin Dryjanski, Ph.D.

Talk Outline

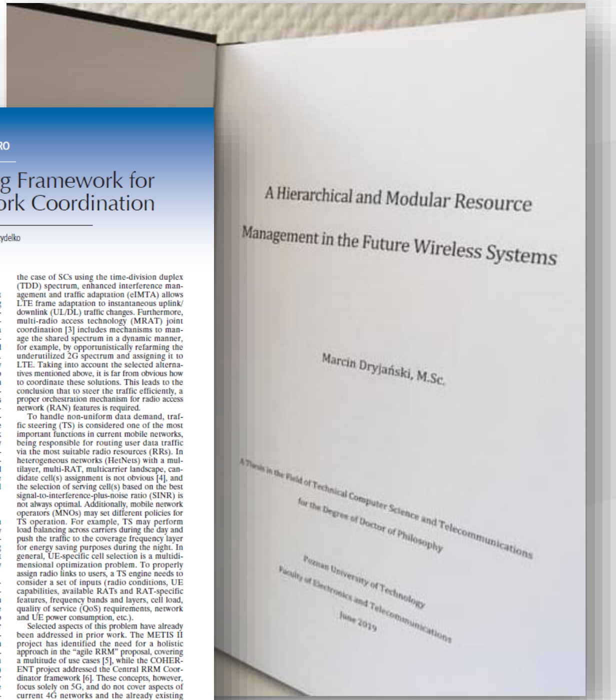
- Evolution of Mobile Wireless Systems
- LTE Complexity
- 5G Complexity
- Mobile Networks Design Approaches
- Unified and Hierarchical Framework
- Conclusions and Summary

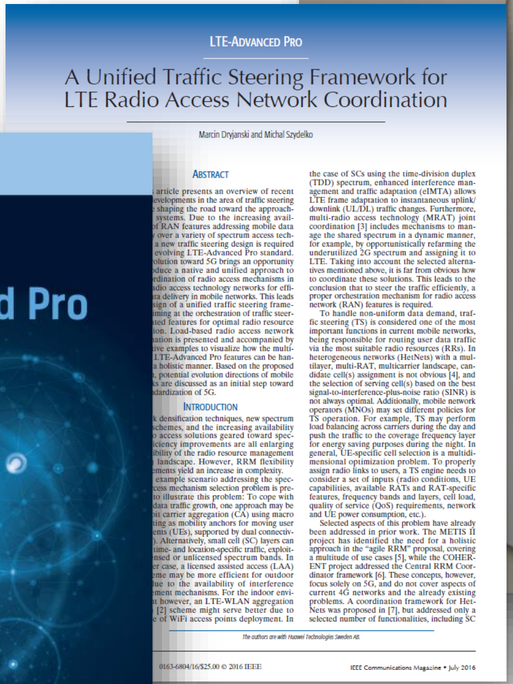
Marcin **Dryjanski, Ph.D.**

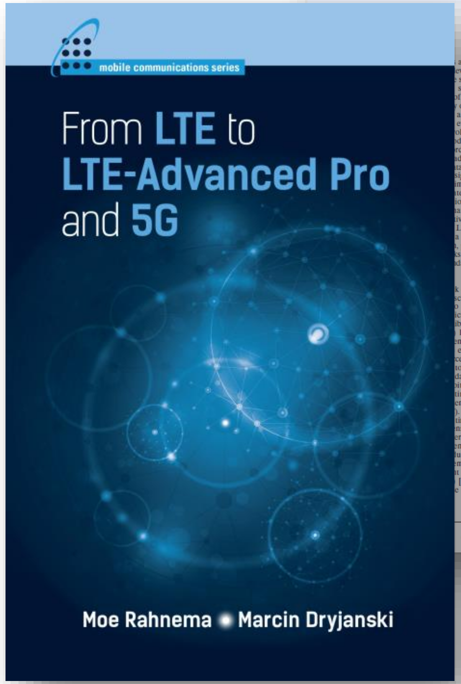
Marcin Dryjanski is the co-founder, principal consultant, and a board member at Grandmetric, where he provides consulting services and training courses on LTE and 5G-related topics, as well as leads company's wireless research on Grandmetric's IoT platform.

Marcin has held Senior IEEE Membership since 2018 and has served as a R&D Engineer, Lead Researcher, R&D Consultant, Technical Trainer and Technical Leader. He earned a Ph.D., with honors, from Poznan University of Technology in 2019.

Marcin has co-authored several research papers targeting LTE-Advanced Pro and 5G radio interface design, and is co-author of a book "From LTE to LTE-Advanced Pro and 5G" published by Artech House. Marcin was a Work Package leader in 5GNOW, a EU-funded research project aiming at radio interface design for 5G.

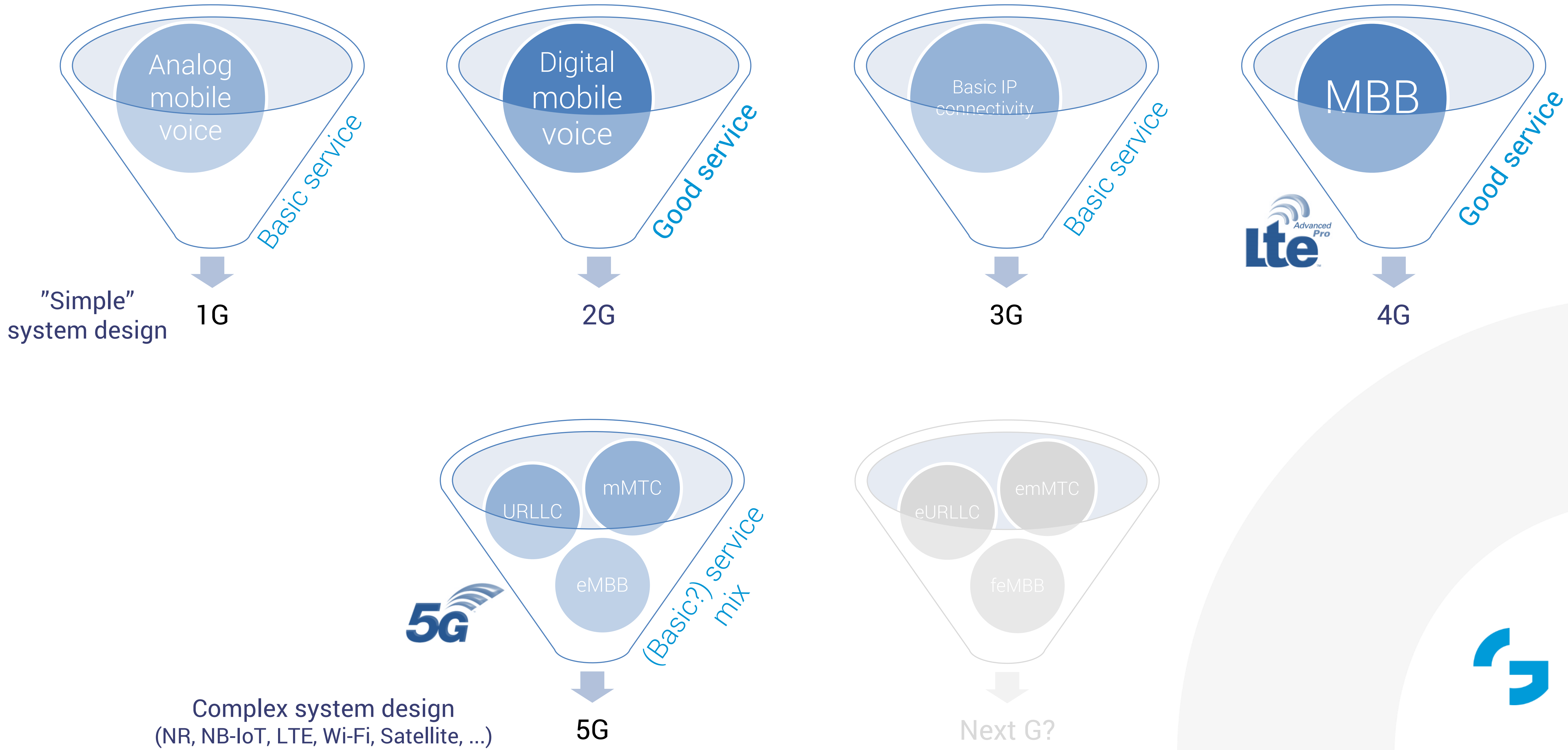






Evolution of Mobile Wireless Systems

Mobile Wireless Systems – **Evolution**



Beyond 5G – **Shall We?**

Will 5G evolve into an umbrella of technologies (NR + LTE + NB-IoT + …) where new features are added over time?

Or do we need next G's…?

LTE Complexity

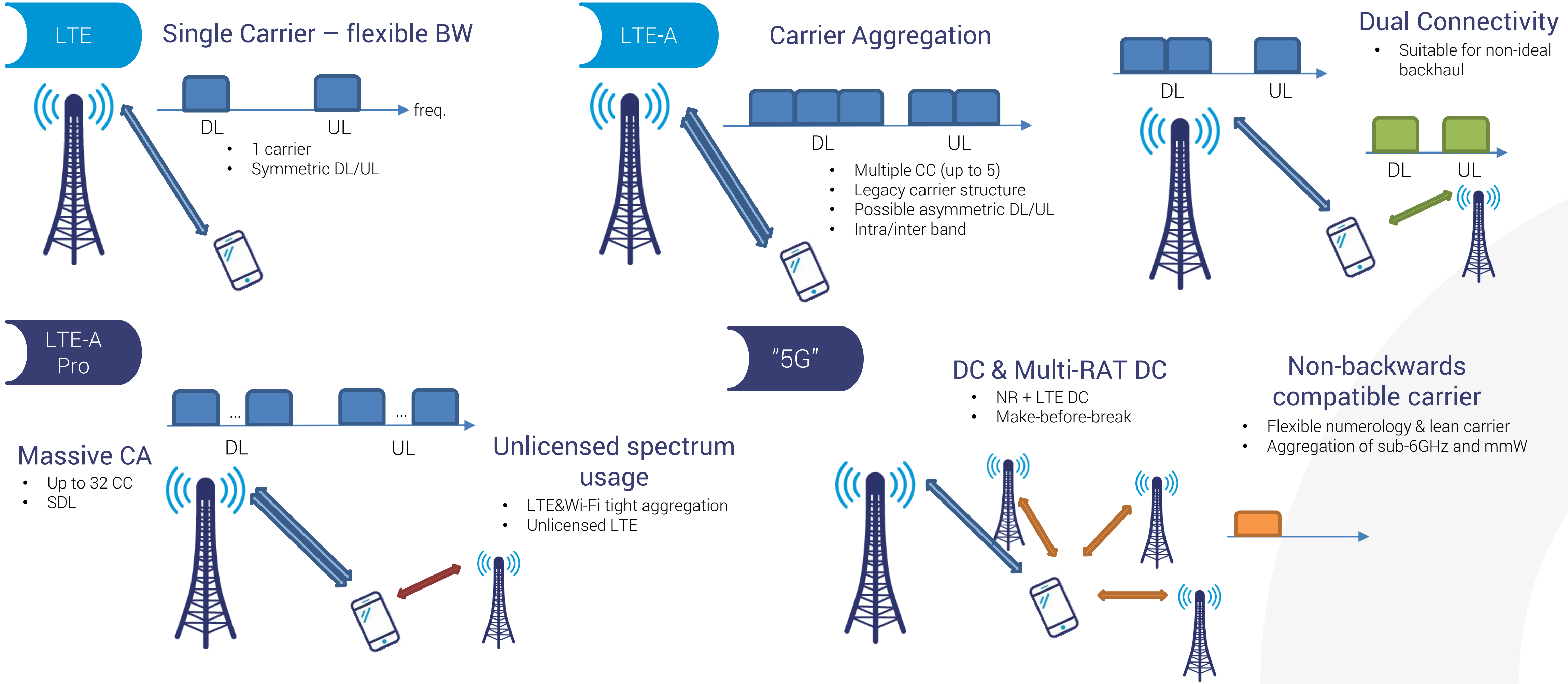
LTE-Advanced Pro – **An "Evolved" LTE**

- IoT: NB-IoT, LTE-M
- Licensing: LTE-U, LAA, MuLTEfire, LSA, CBRS
- More resources: Massive CA, DC
- WiFi access: LWA, RCLWI, LWIP
- Resource allocation flexibility: eIMTA, short TTI
- Direct connectivity: V2X, D2D, ProSe
- ...

LTE Evolution – Spectrum Toolbox

Spectrum Toolbox

- Frequency bands
- Spectrum aggregation
- Duplexing schemes
- Spectrum licensing and sharing schemes
- Spectrum refarming



Ref.: Szydelko M., Dryjanski M. "Spectrum Toolbox Survey: Evolution Towards 5G", CrownCom 2016

LTE Evolution – Spectrum Toolbox

3GPP Release / Toolbox Element	LTE: Rel-8, 9	LTE-Advanced: Rel-10, 11, 12	LTE-Advanced Pro: Rel-13,14	5G Phase I: Rel-15 5G Phase II: Rel-16
Frequency bands [GHz]	0.7, 0.8, 1.8, 2.1, 2.3-2.4, 2.5-2.6GHz	0.45 (Brazil), Digital Dividend, 1.5, 3.4-3.8GHz	5GHz ISM; WRC-15 bands	New bands below 6GHz for 5G RAT; mmW: 6-100GHz; WRC-15/19 bands
Spectrum aggregation	Single Carrier (1.4-20MHz), symmetric DL/UL	Dual Connectivity, CA variants: -up to 5CC, FDD and/or TDD -intra-/ inter-band, (non)-continuous, -Co-located, RRH -asymmetric DL/UL	Massive CA (32CC), LAA (5GHz), LWA, eLWA, SDL for CA: 2.3-2.4GHz	Multi-Connectivity with asymmetric DL/UL, SDL for CA: 700MHz, 2.5-2.6GHz, NR-LTE DC
Spectrum licensing schemes	Licensed spectrum only	Licensed, Carrier Wi-Fi	Licensed, Unlicensed, DL LAA, LWA, LSA, eLWA	Co-existence of: LSA, exclusive licensed, shared license-exempt spectrum, enhanced LAA (DL+UL), CBRS
Duplexing schemes	Separate FDD, TDD	FDD and TDD (CA-based), eIMTA	FDD Flexible Duplex	Flexible TDD
Sharing schemes (network, spectrum)	Static schemes (MOCN, MORAN)	Static schemes (MOCN, MORAN)	RSE, LSA	LSA, NHN, Slicing
Spectrum refarming	Static	Static	Dynamic, DSA, MRAT Joint Coordination	Dynamic, opportunistic, "CR"

Ref.: Szydełko M., Dryjanski M. "Spectrum Toolbox Survey: Evolution Towards 5G", CrownCom 2016

LTE Evolution – **Pros & Cons (Examples)**

Feature	Advantages and opportunities	Disadvantages and challenges
Carrier Aggregation	• Improves user throughput and cell capacity • Possibility to aggregate different spectrum bands • Extension beyond single carrier allocation • MAC layer management	• Not possible to aggregate spectrum in non-ideal backhaul RRH deployments • Scheduler complexity (CA and non-CA users)
Massive Carrier Aggregation	• Enables to acquire multitude of bands and BWs to increase capacity and mix licensed with unlicensed bands	• Complex management • Complexity of RF chains • UE support as a limiting factor
Supplemental Downlink	• Possibility to adapt aggregated capacity to the required DL/UL demand • Aggregation and management on MAC	• Feature limited by the available SDL-specific bands • CA-based operation only
Dual Connectivity	• Adds spectrum aggregation opportunity for non-ideal backhaul inter-site • Possible to combine with CA • Enables extension to aggregate multi-RAT aggregation on PDCP level	• Not possible to allocate resources on MAC level • May have problems at anchor cell boundary due to both Macro and SC change • Requires additional scheduler

Ref.: M. Szydelko, M. Dryjanski, "Spectrum Toolbox Survey: Evolution Towards 5G", EAI Endorsed Transactions on Cognitive Communications, Vol. 3, Issue 10

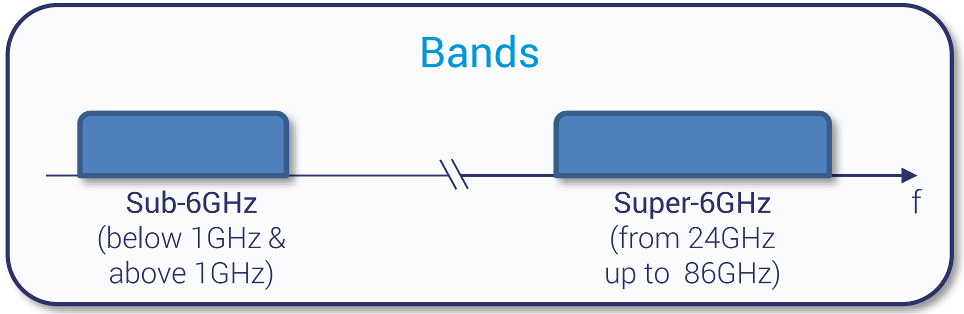
Technology Evolution – **Not Really Successful(?)***

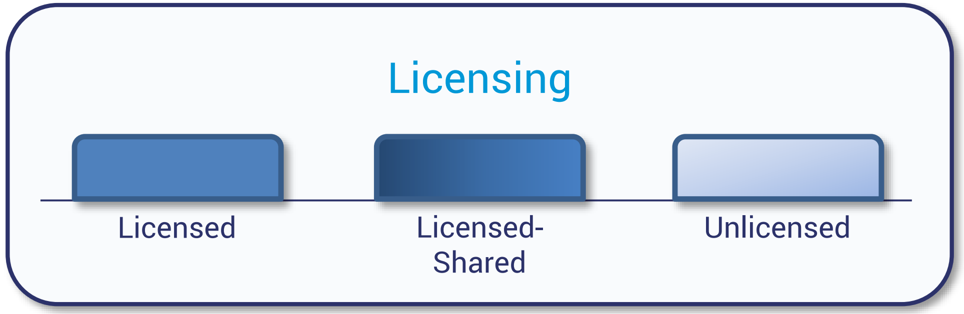
- MBMS/eMBMS
- LTE-U
- Small Cells (so far)
- LWA
- CoMP
- Relaying

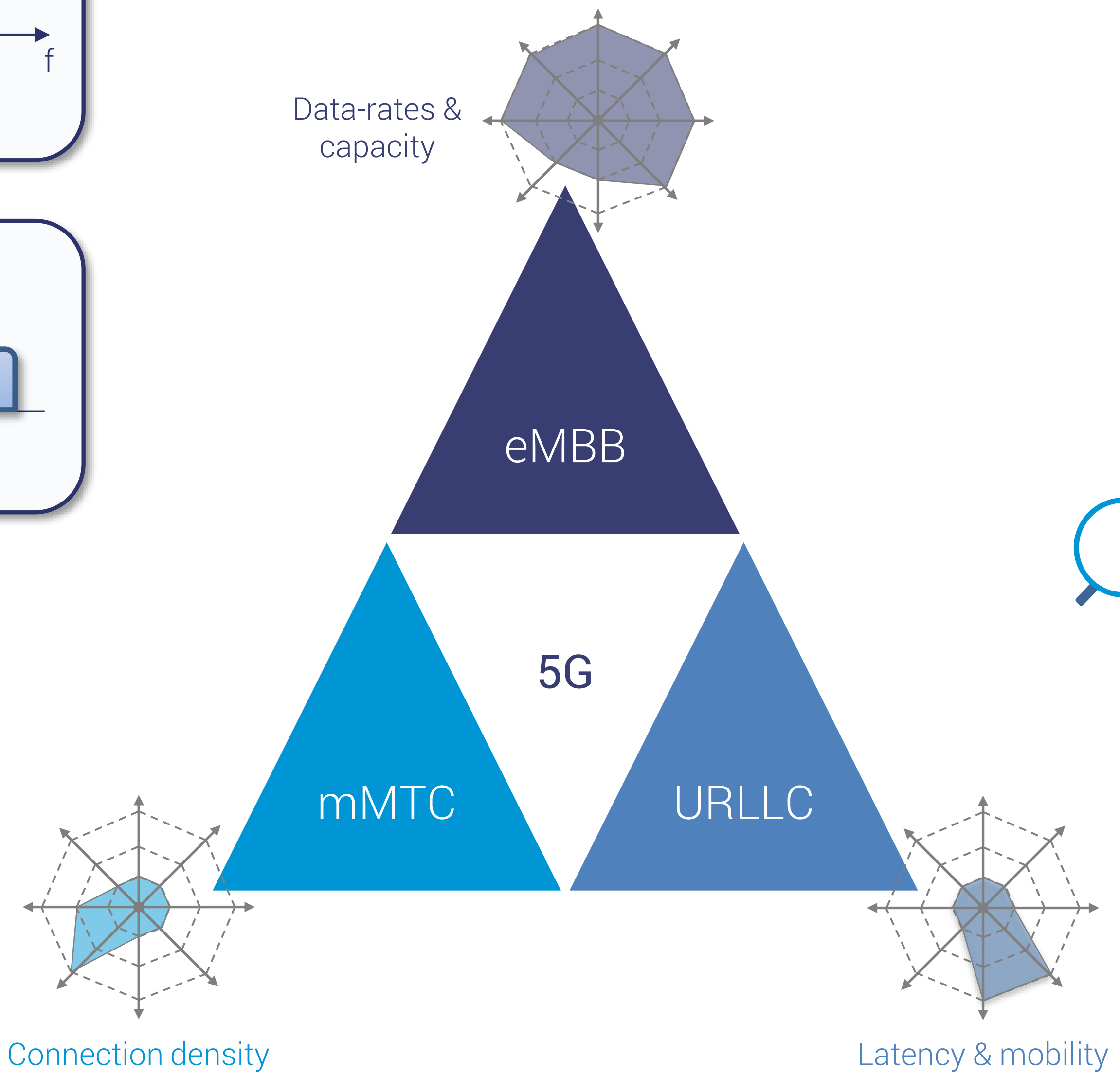
* Personal opinion

5G Complexity

5G Spectrum, Services and Techniques



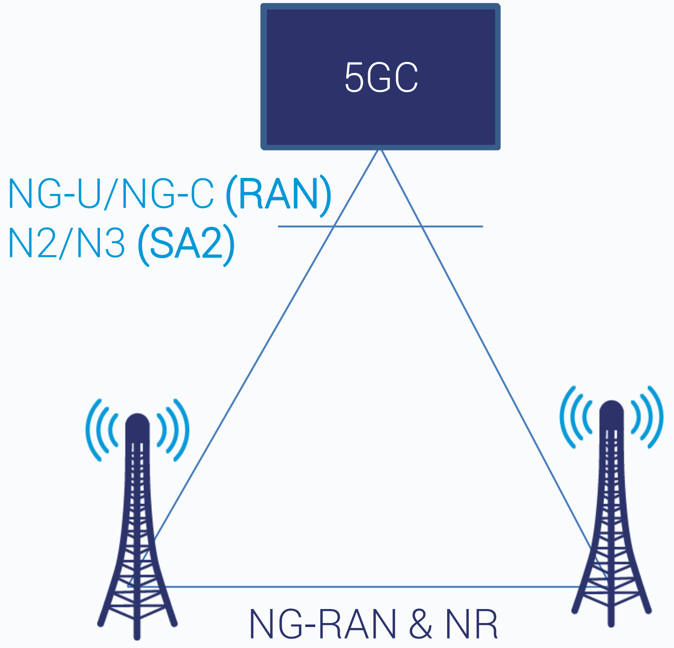




- mmWave, MMIMO
- Flexible numerology
- CP/UP split, Slicing, CRAN
- Unlicensed, Satellite access
- D2D, V2X
- LTE & NR integration options
- SON, SDN, NFV

5G Standards – Complexity of the System

Naming - Architecture



Compared to:
EUTRAN
EUTRA
EPC
EPS

Dual Connectivity options

EN-DC	E-UTRA-NR Dual Connectivity
MR-DC	Multi-RAT Dual Connectivity
NE-DC	NR-E-UTRA Dual Connectivity
NGEN-DC	NG-RAN E-UTRA-NR Dual Connectivity

L1 parameters

Few weeks before freezing **5G NSA**, RAN1 sent RAN2 ~**600 L1** parameters to cover within RRC spec.
(compared to ~**80 L1** parameters for **LTE Rel-8**)

5G Standards – **How Do We Call This One?**

1G	2G	3G	4G	5G
BS (Base Station)	**BTS** (Base Transceiver Station)	**NB** (NodeB)	**eNB** (evolved NodeB)	**gNB** (next generation NodeB) **but also:** en-gNB ng-eNB gNB-DU lls-gNB-DU …

What we can end up with: even-further-enhanced lower-layer-split next-generation-NodeB distributed-unit (efe-lls-gNB-DU)

Systems Complexity **Summary**

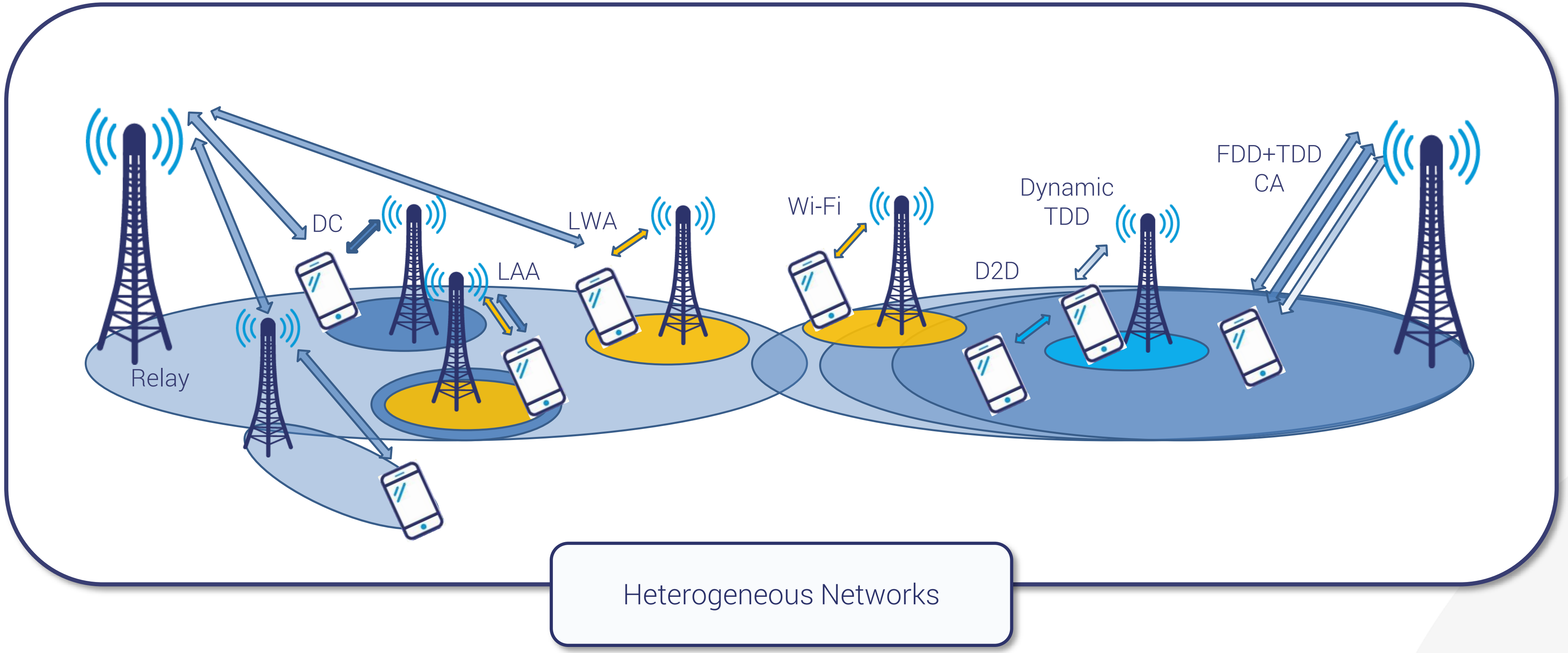
LTE complexity reasons:

- LTE has been equipped with a lot of "add-ons" along seven 3GPP releases: NB-IoT, eMTC, LAA, LWA, DC, V2X, D2D, CA, CoMP, FD-MIMO, LSA, CBRS, short TTI, …

5G complexity reasons:

- bigger scope of use cases to be covered,
- set of technologies to be brought under the 5G umbrella,
- NR to natively bring LTE features with forward compatibility and flexibility as design principles,
- LTE being part of 5G.

Current Landscape – **RRM Complexity**



Ref.: Szydelko M., Dryjanski M. "Spectrum Toolbox Survey: Evolution Towards 5G", CrownCom 2016

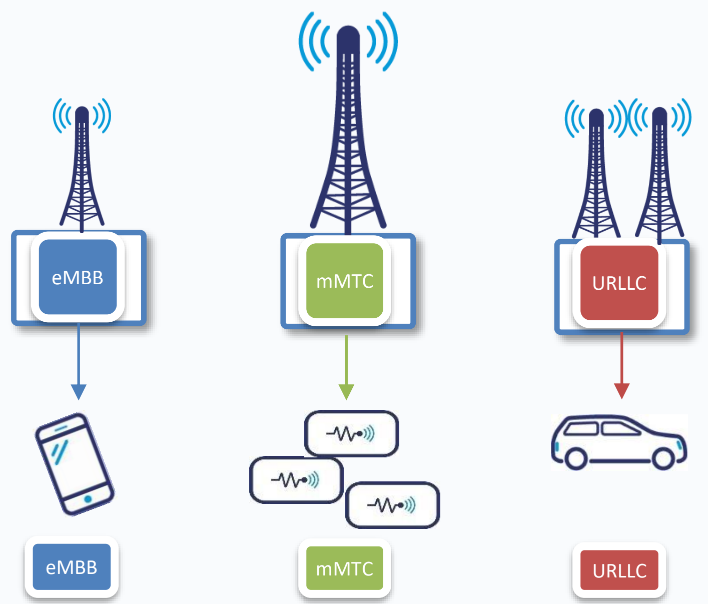
A big challenge for Radio Resource Management of Multi-RAT/HetNet!

Mobile Networks Design Approaches

Design Approaches – **Three Designs**

Approach 1: Fragmented solutions for individual use cases

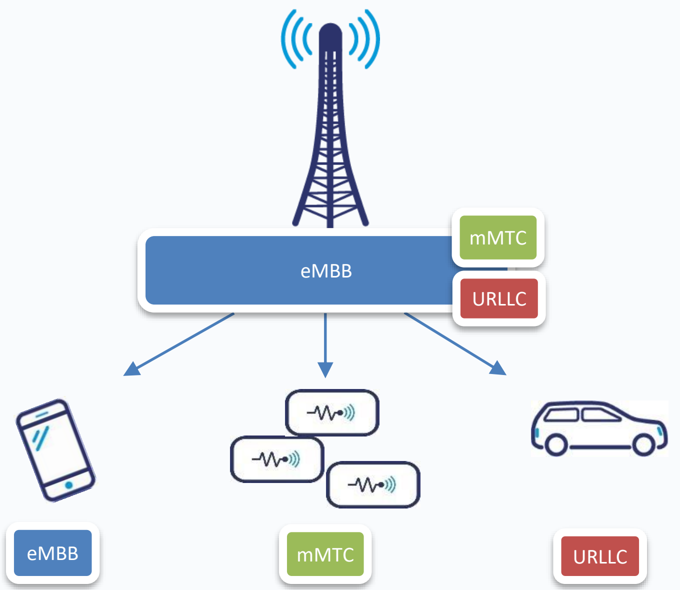
5G is a set of very diverse applications / requirements



Design separate systems to realize different requirements.
(like in IoT landscape)

Approach 2: "One-size-fits-all" / One design

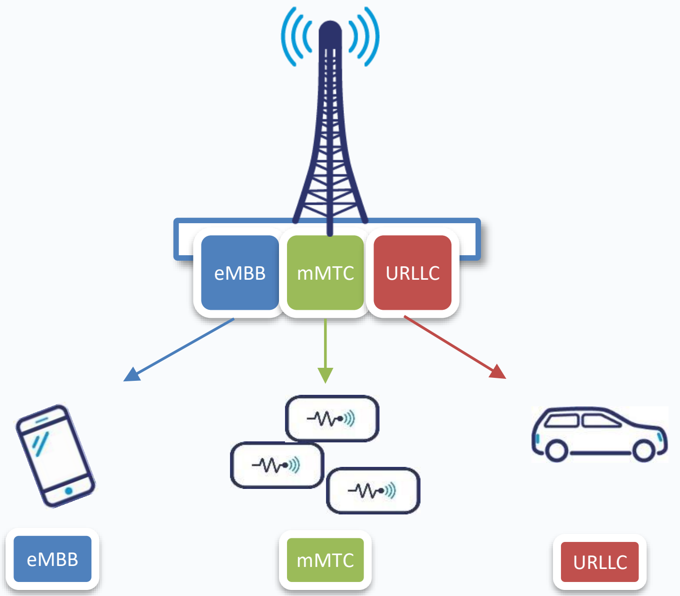
5G is all about IP services (one „use case")



Evolve existing systems with add-on features to realize particular needs.
(like LTE)

Approach 3: Hybrid and optimized set of tailored designs with unified management

Diverse requirements jointly managed



Natively unified and hierarchical approach to the design of the system.

Design Approaches – **Solution vs Purpose**

- Short range *vs.* Local area *vs.* Wide area e.g., in IoT space:
  - Bluetooth, BLE (smartwatch, mouse, pointer) *vs.*
  - Wi-Fi, Zigbee (indoor Internet access, energy management, home monitoring) *vs.*
  - LTE, NB-IoT/LoRa/Sigfox (e.g., outdoor Internet access, Smart City)
- Indoor *vs.* outdoor e.g., Wi-Fi *vs.* cellular for Internet access
- High ”speed” *vs.* low ”speed” (content vs sensing) e.g., LTE *vs.* NB-IoT, Wi-Fi *vs.* Zigbee
- Adaptive *vs.* fixed e.g., dynamic content sharing *vs.* predefined periodic updates
- Local *vs.* global e.g., handled by gateways *vs.* directly communicating to network

Design Approaches – **Observations**

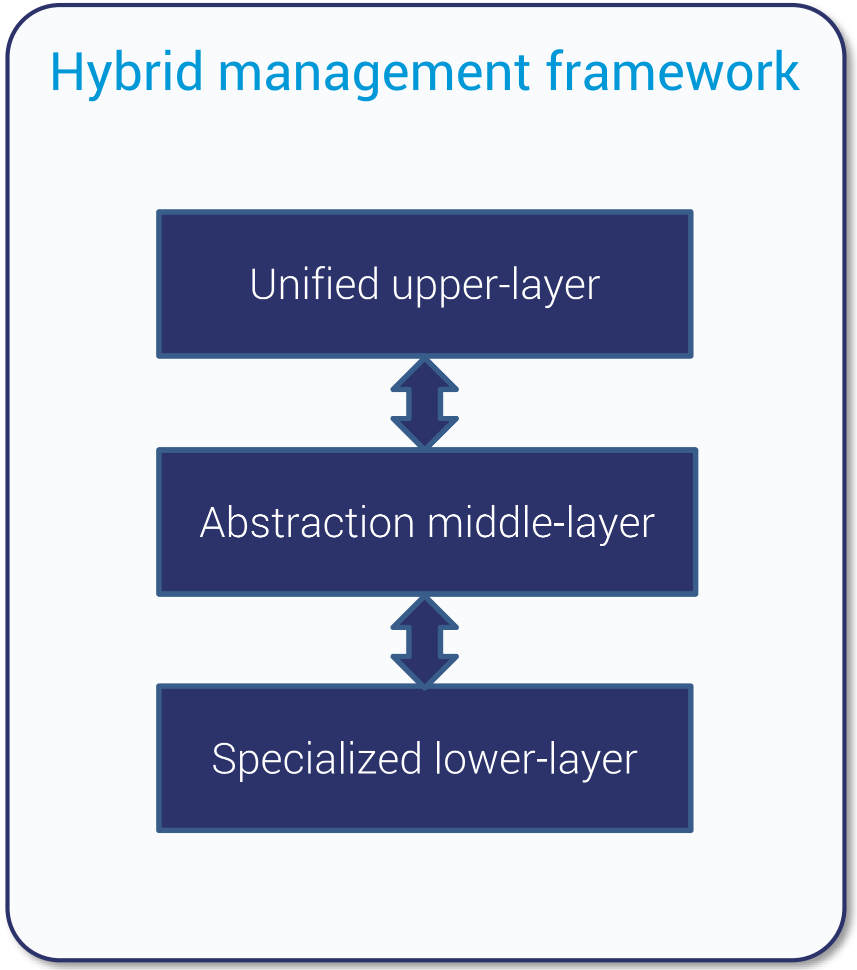
- There are diverse requirements and diverse services
- There are systems supporting different services tailored to them
- There are different approaches suited for different purposes
- We will never know all the services in advance
- Designing a system that is suitable for everything at once is difficult, hard to manage and typically results in over-dimensioning

The way to go is to take the design approach with flexibility, forward compatibility, and easy ”pluginability”, keeping in mind that we will NOT know all the requirements in advance!

Unified and Hierarchical Framework

Unified & Hierarchical – **Framework Design**

Handling the heterogenity of: RATs, spectrum, devices, service mixes and features by a framework being a hybrid mechanism.
“One-size-fits-all” is no longer true → rather coordinate multiple features and technologies optimized for specific requirements.

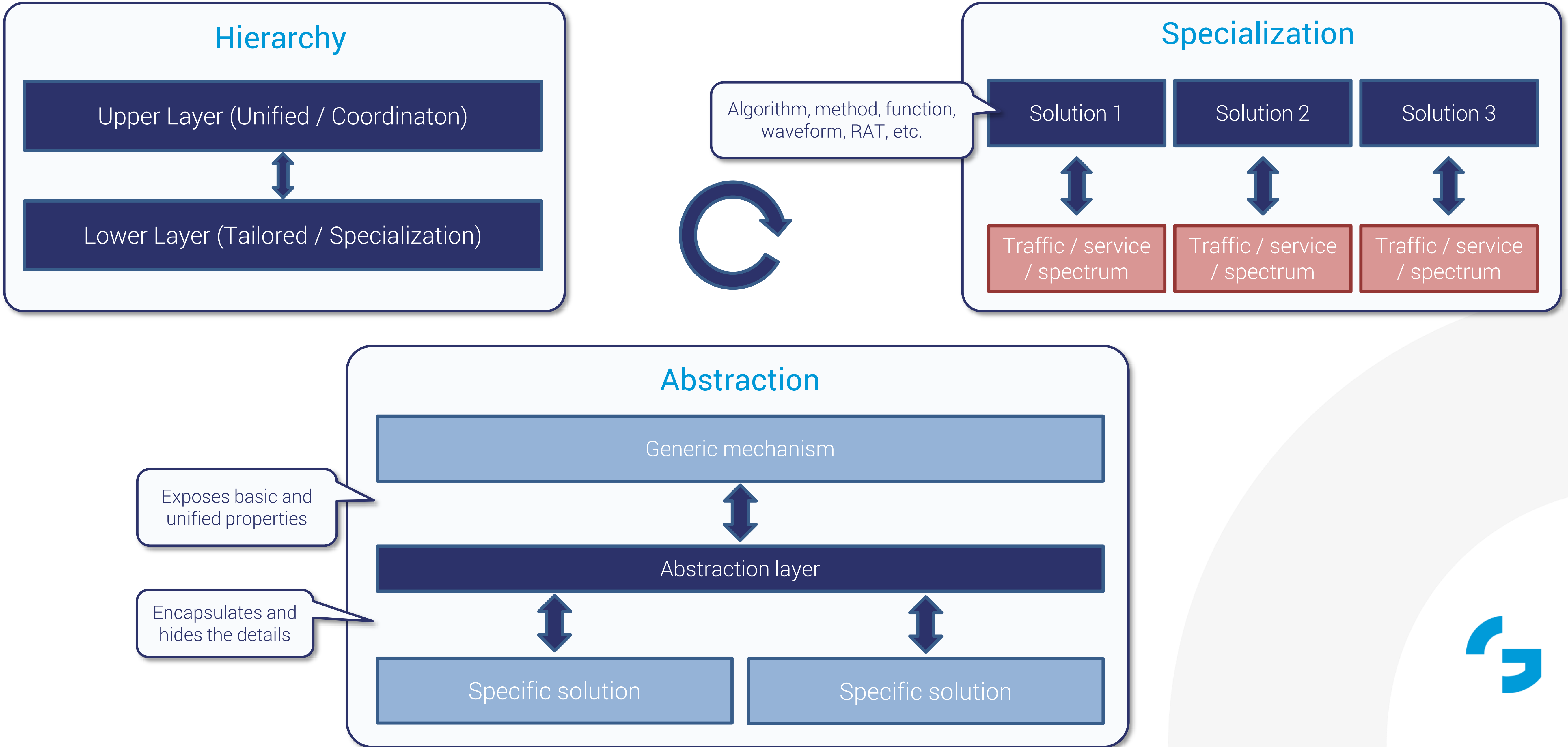


handling the context independently of the underlying technology

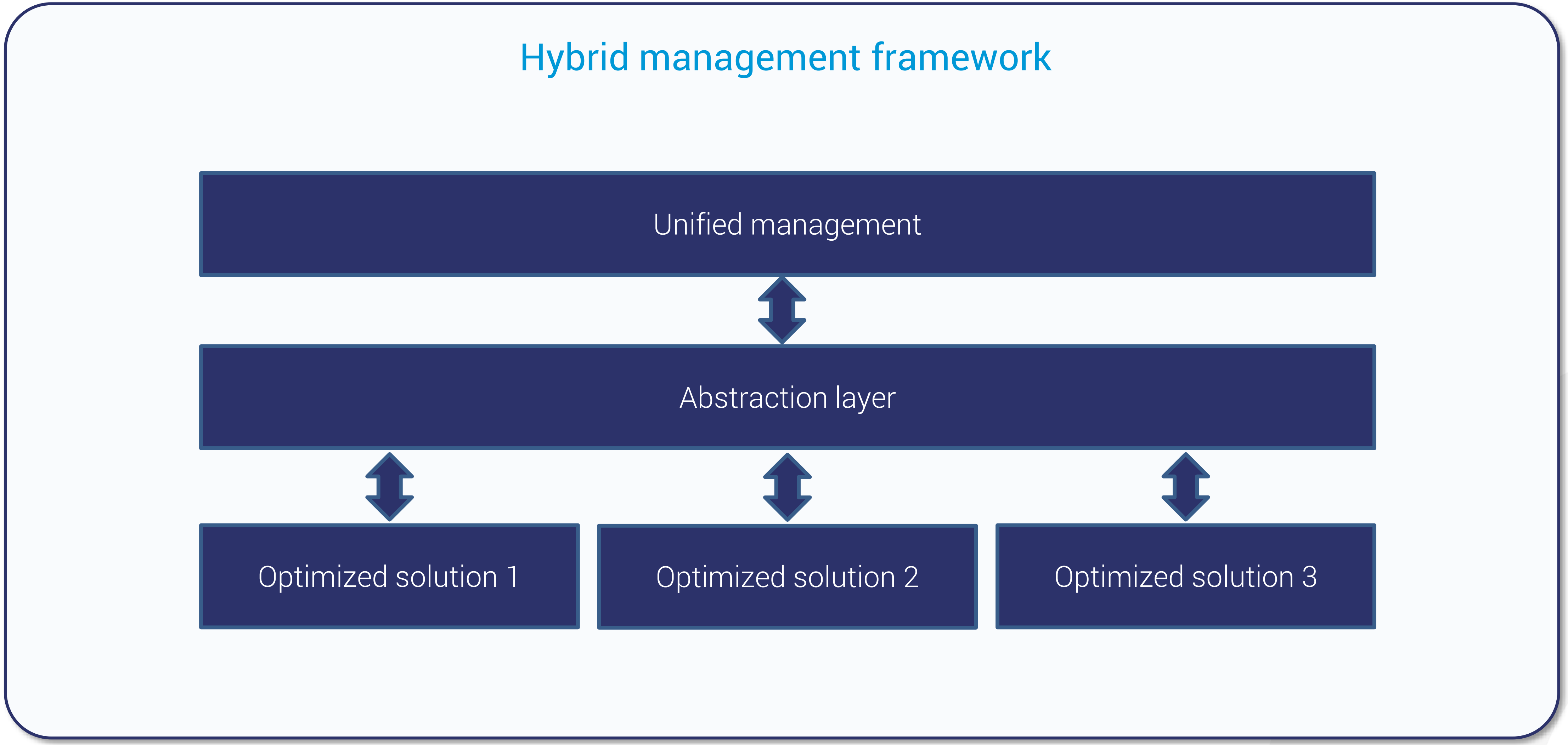
enabling an “easy” add-on of the specialized techniques

best serving a particular purpose

Unified & Hierarchical – **Principles**

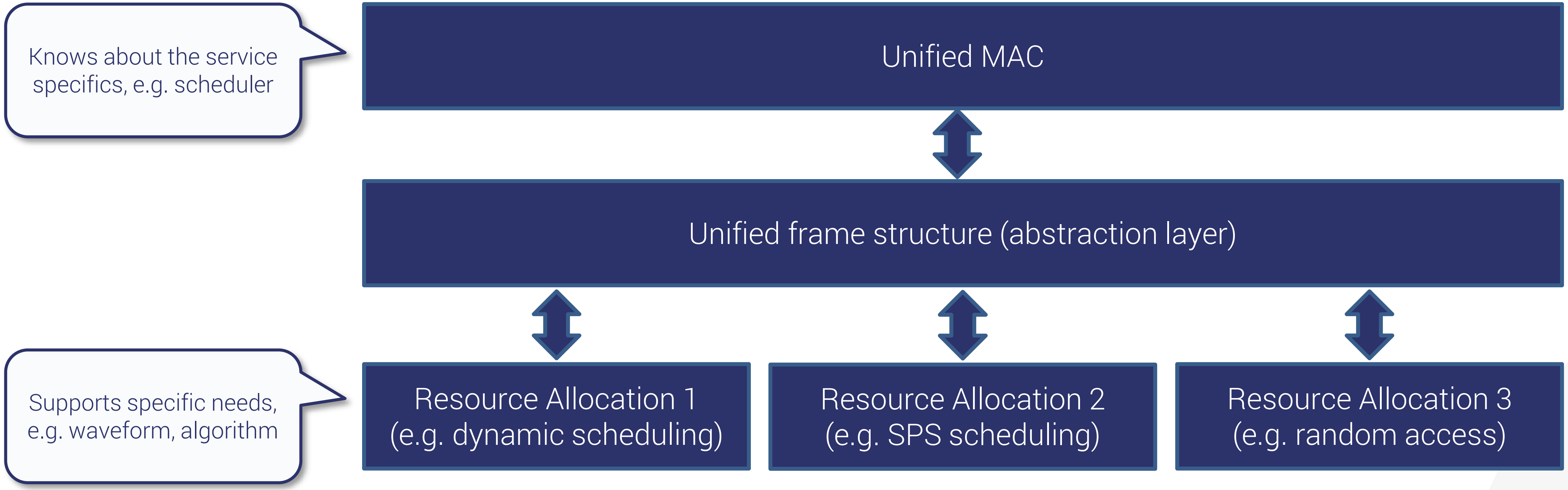


Unified & Hierarchical – **Generic Framework**



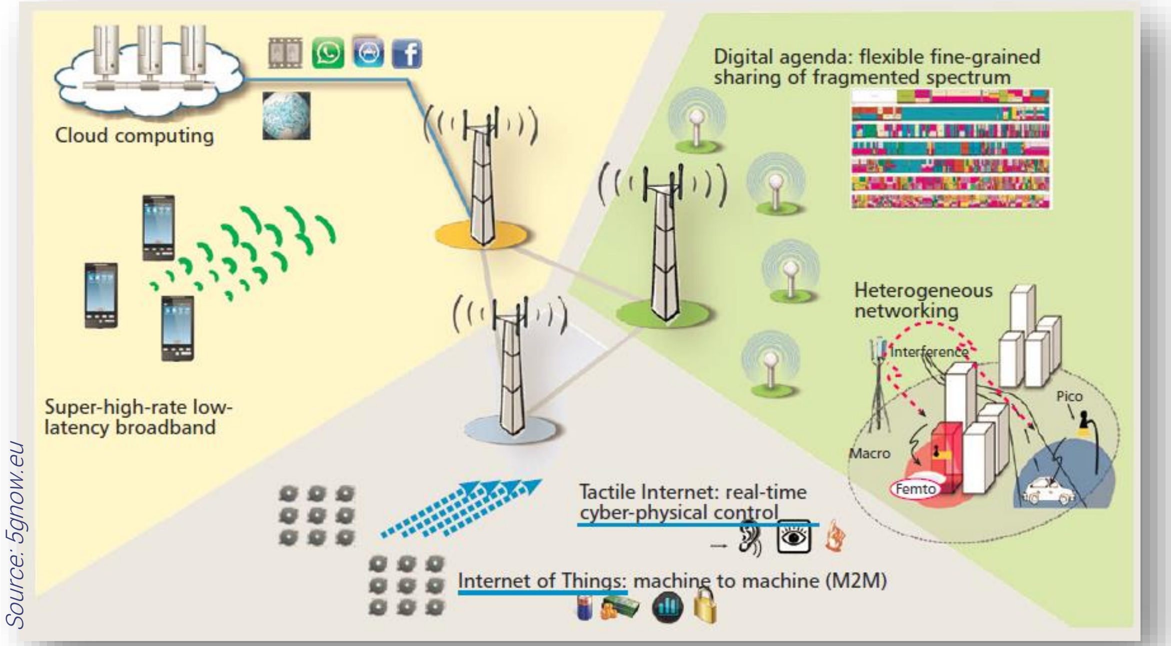
Unified and Hierarchical Framework Examples

Unified & Hierarchical – **Unified MAC**



Unified & Hierarchical – **5GNOW Example**

5GNOW Use Cases and Requirements



Future radio access:

- Flexible
- Scalable
- Reliable
- Robust
- Content aware

5GNOW Solutions

5GNOW PHY
Non-orthogonal waveforms

- FBMC
- GFDM
- UFMC
- BFDM

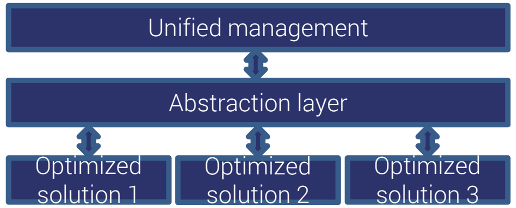
5GNOW PHY-to-MAC I/F
Mixture of synchronous and asynchronous traffic

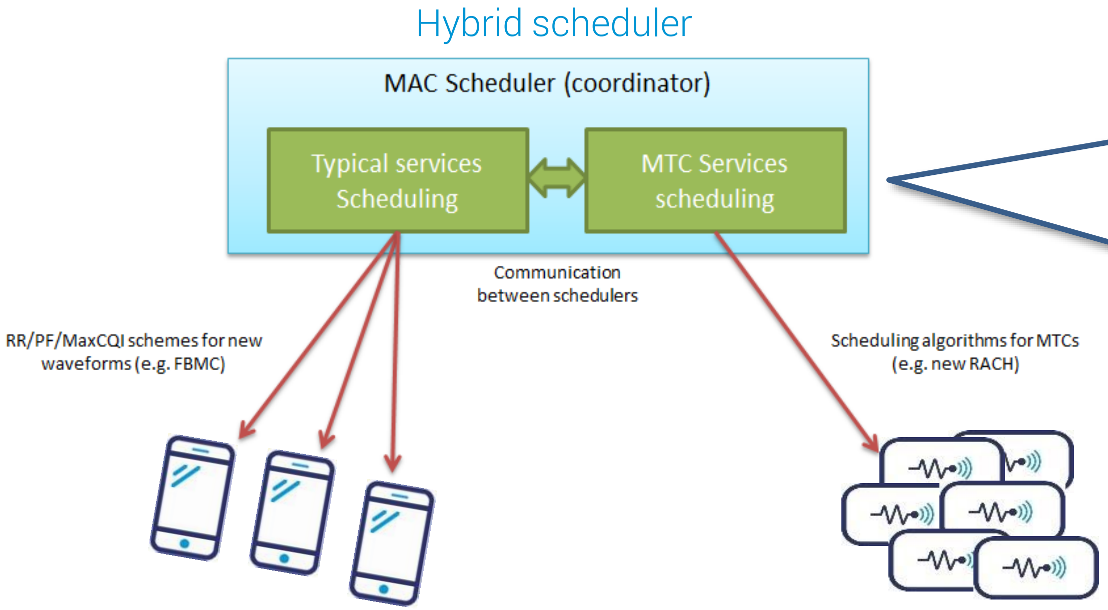
- Unified Frame Structure

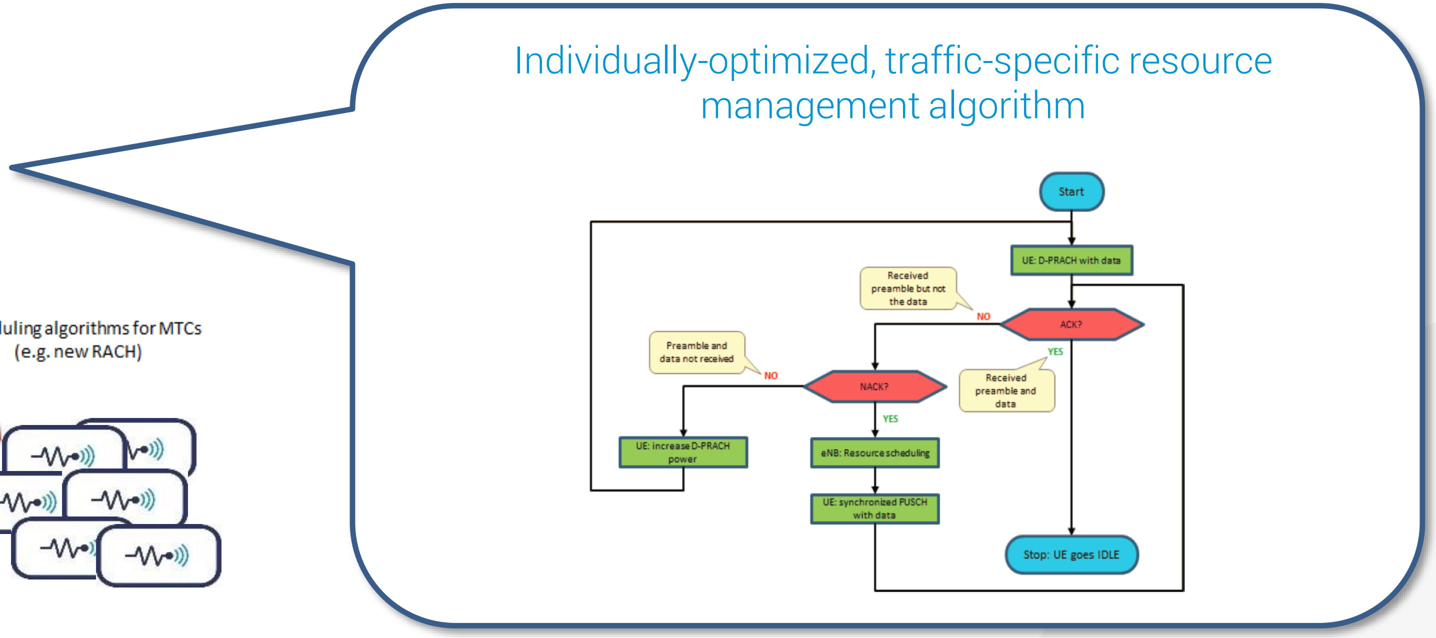
5GNOW MAC
Hybrid and hierarchical

- Unified MAC

Unified & Hierarchical – **5GNOW Example**

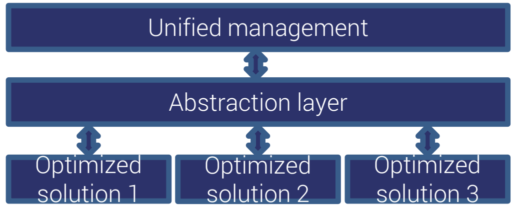




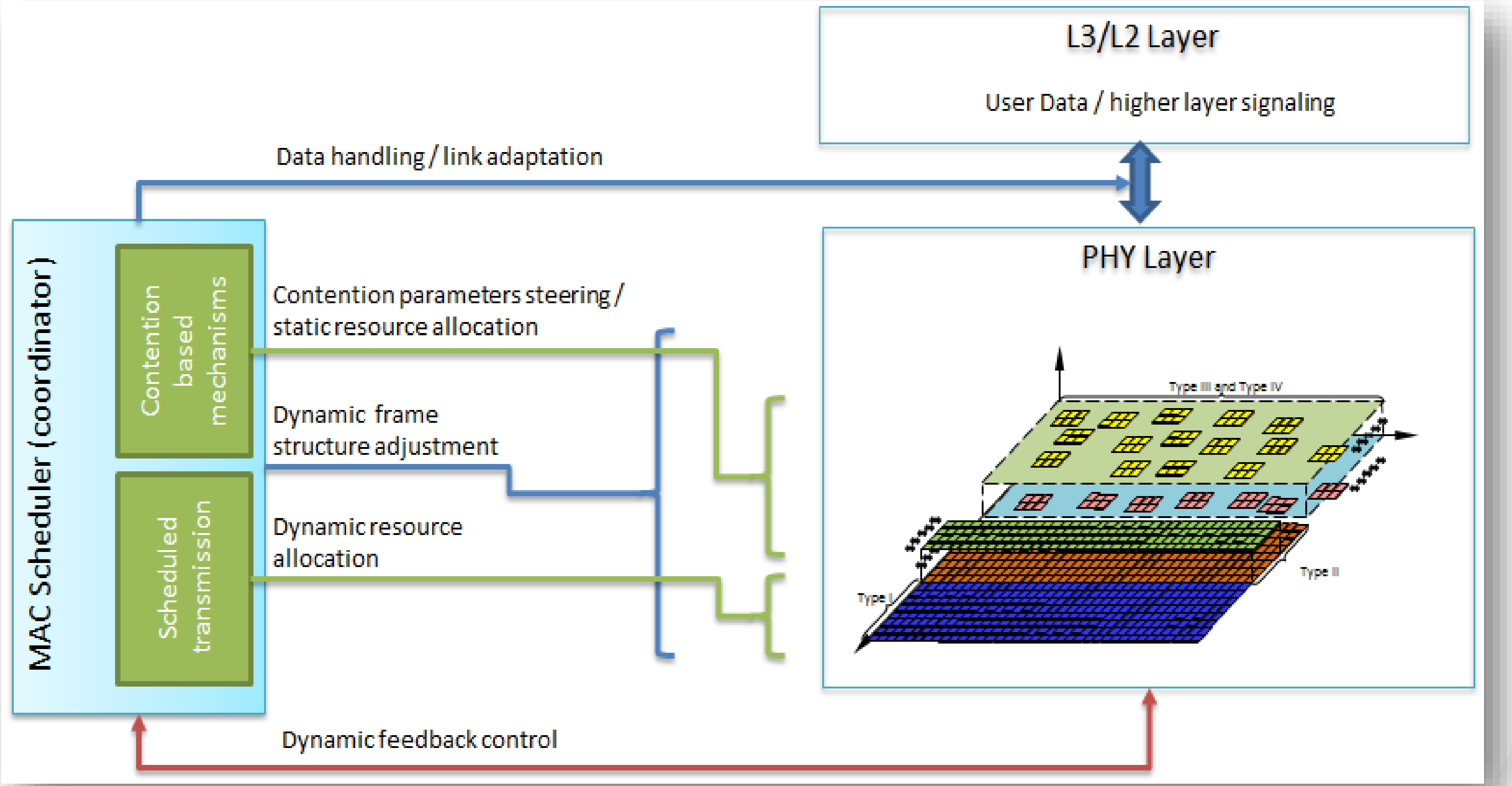


Source: 5gnow.eu

Unified & Hierarchical – **5GNOW Example**

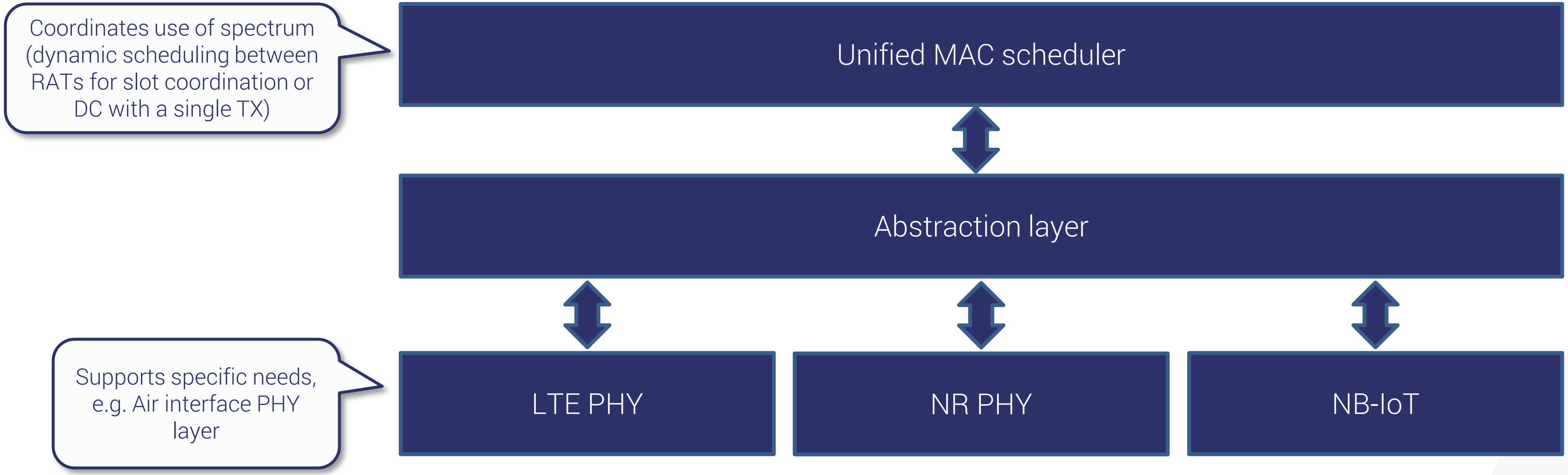


5GNOW Unified MAC Interfacing with Unified Frame Structure



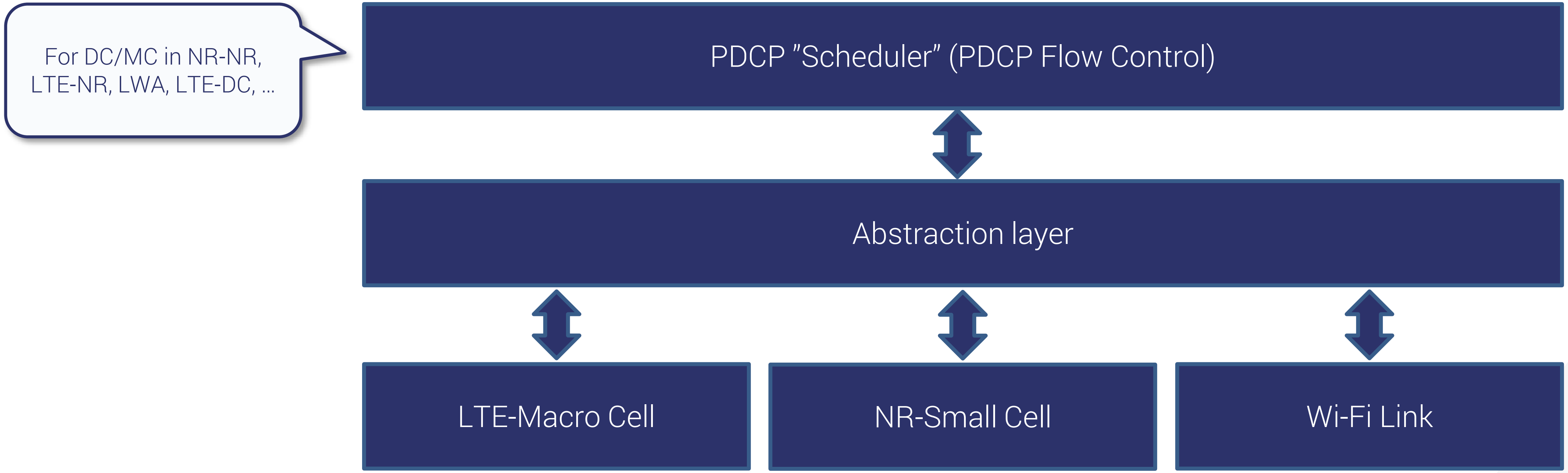
Source: 5gnow.eu

Unified & Hierarchical – **Unified MAC v.2**

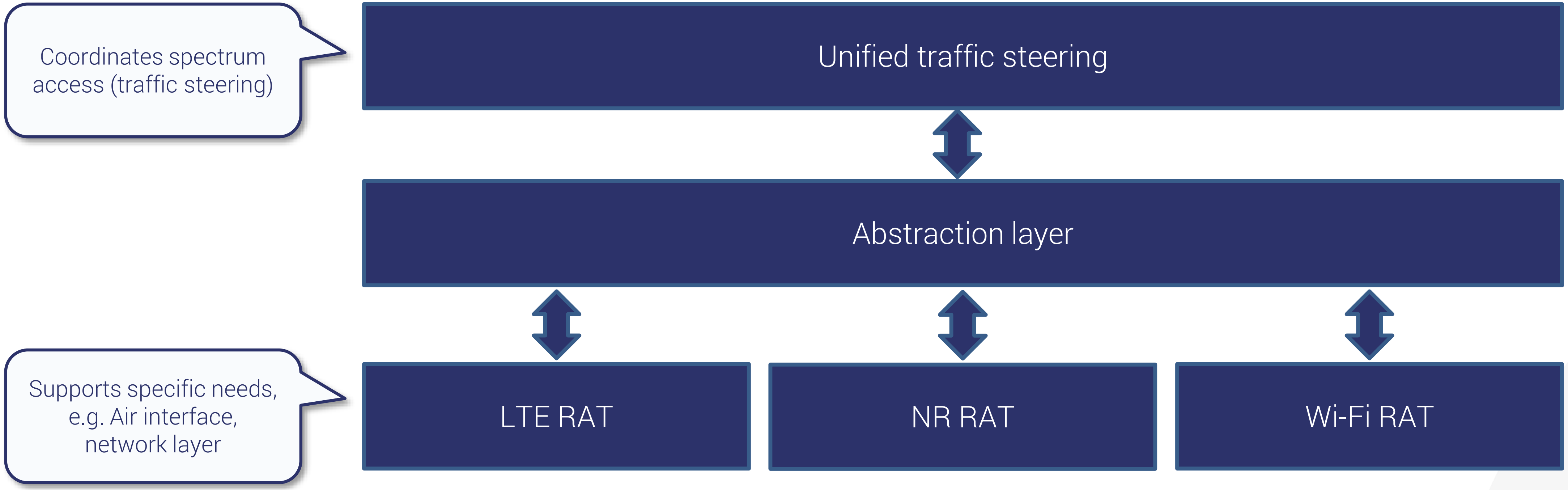


Spectrum coexistence between NR and LTE calls for hierarchical scheduler for subframe coordination

Unified & Hierarchical – **PDCP Scheduler**

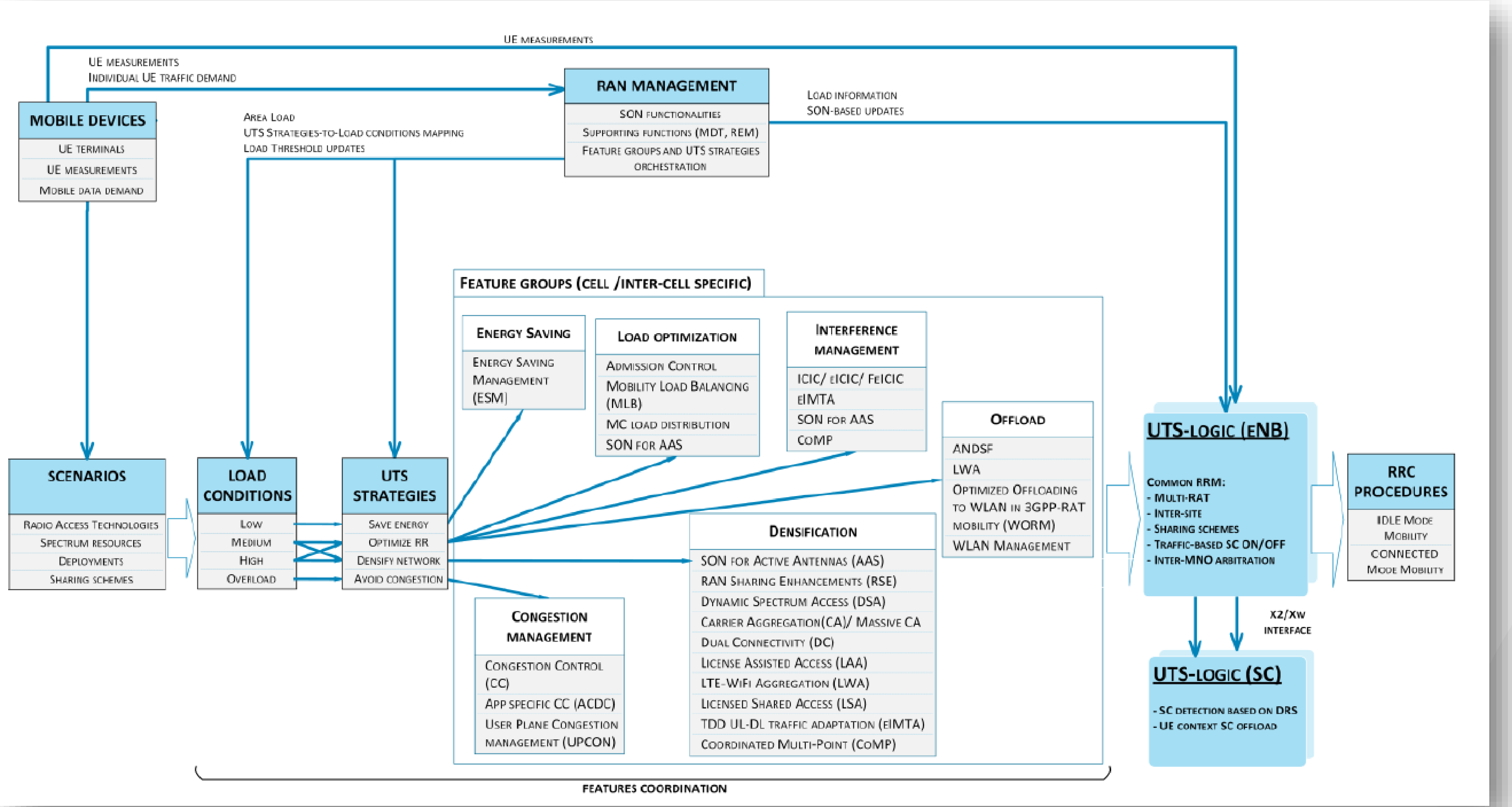


Unified & Hierarchical – **Unified Traffic Steering**



Unified & Hierarchical – **UTS Example**

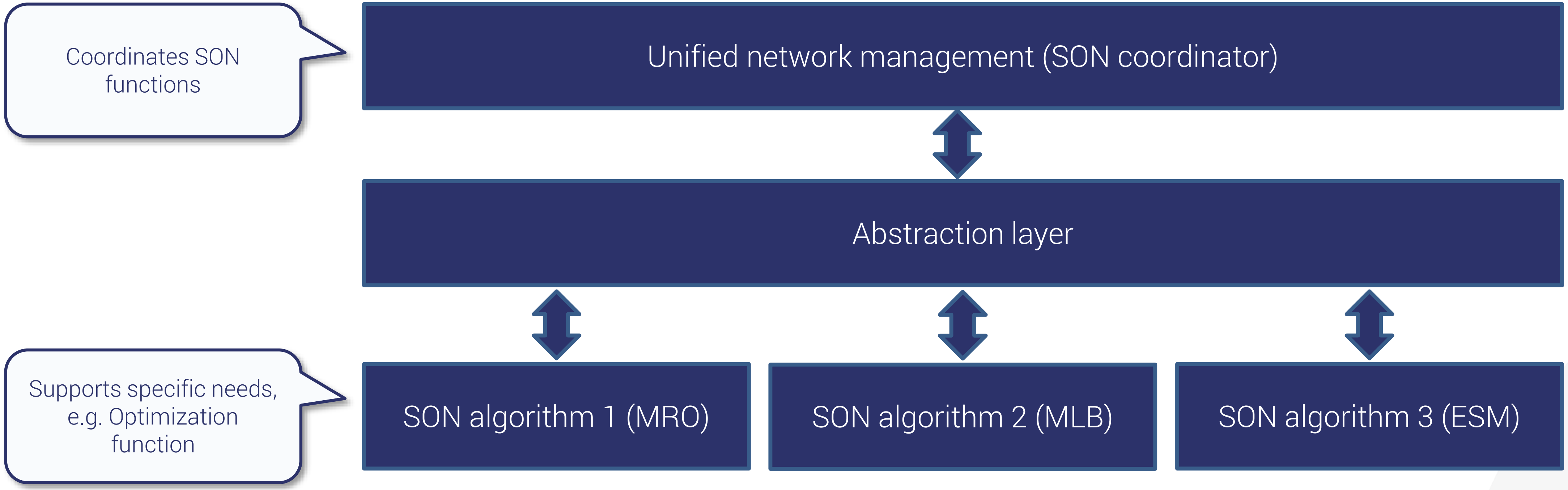
Unified Traffic Steering Framework



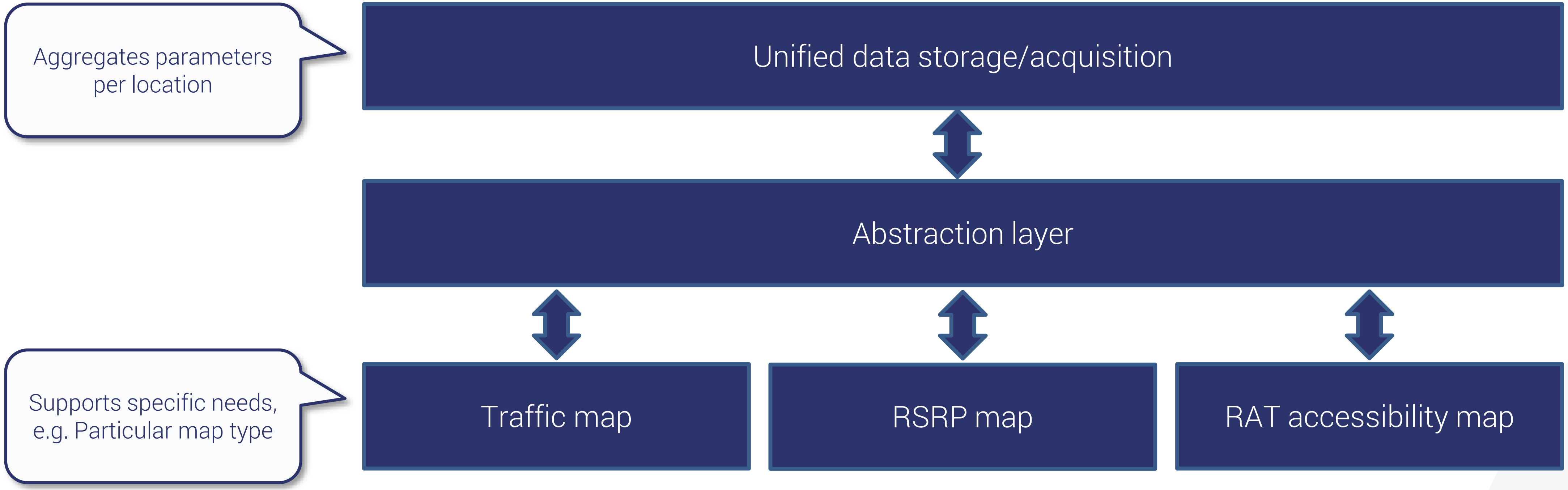
New aspects can be incorporated in a straigth-forward manner:

- Load metrics
- Available features
- Available RATs/layers
- Available strategies
- Available procedures

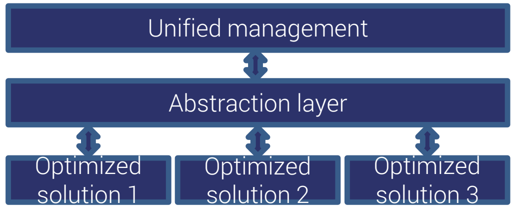
Unified & Hierarchical – **SON Coordination**



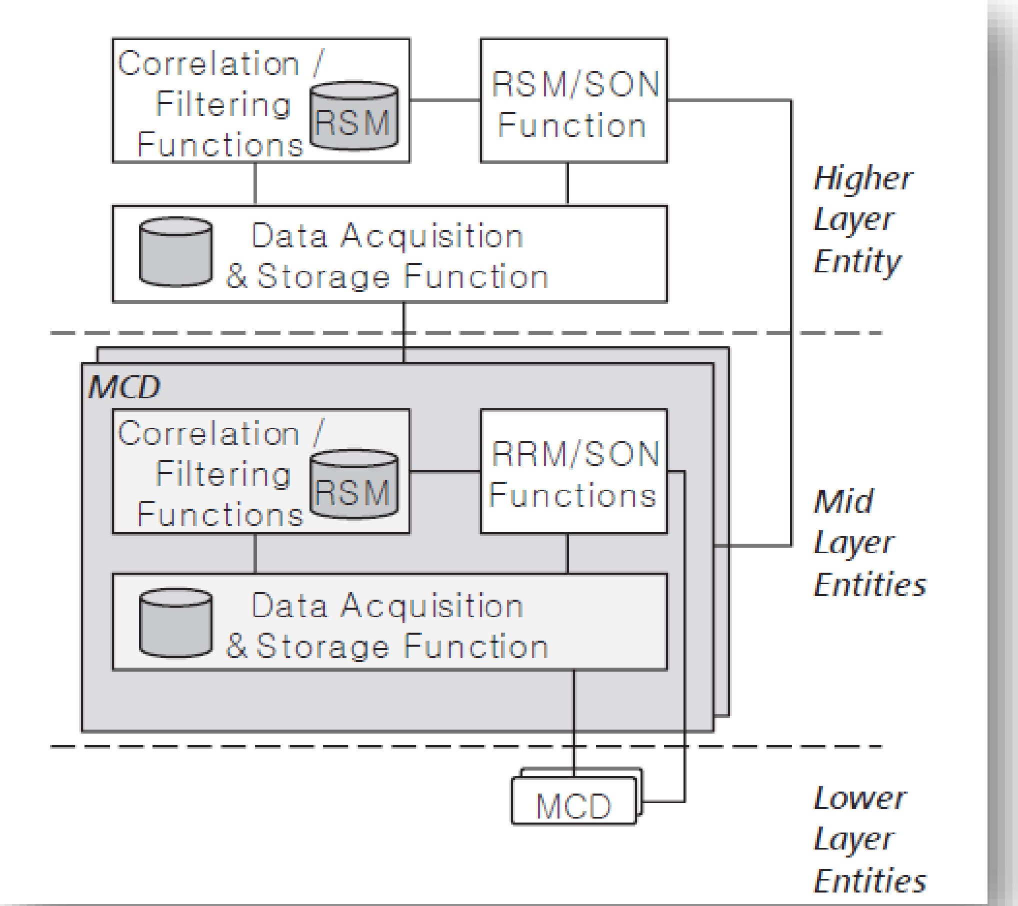
Unified & Hierarchical – **Radio Service Maps**

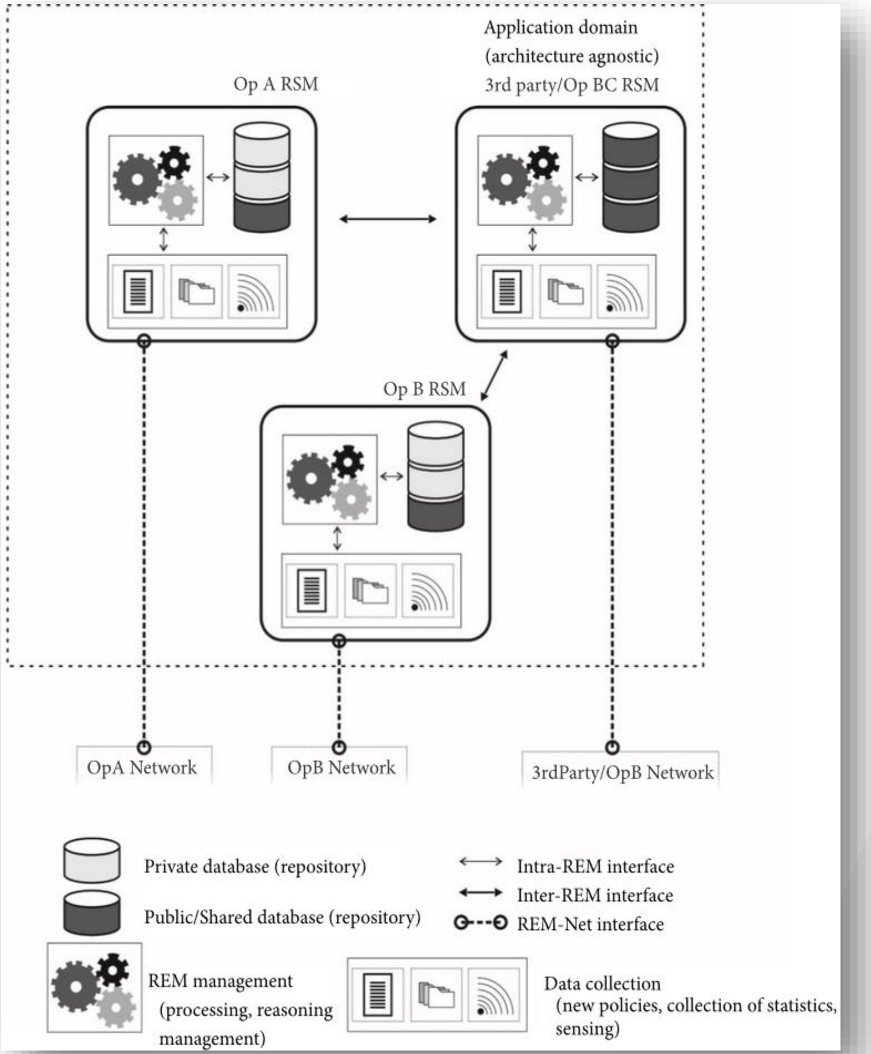


Unified & Hierarchical – **RSM Example**



Architectures





Ref.: P. Kryszkiewicz, A. Kliks, Ł. Kułacz, H. Bogucka, G. Koudouridis, M. Dryjański, "Context-Based Resource Management and Orchestration in 5G Wireless Access Networks", Hindawi WCMC

Same maps could support different features:

- Low level RRM (scheduling)
- Upper level RRM (TS)
- SON (MLB)
- Orchestration (Network layers)

Unified & Hierarchical – **Example IT Analogy**

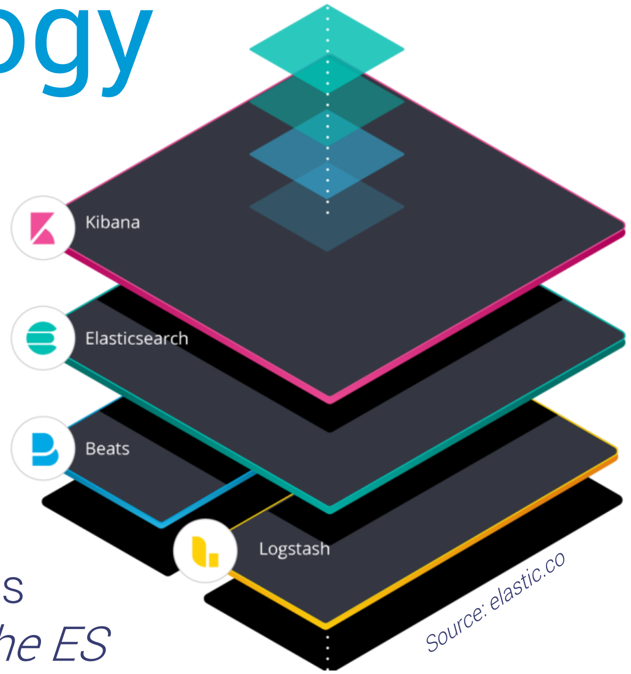
- *Elastic Stack* – monitoring & analytics system

- Architecture:
  - Visualization module – *Kibana*
  - Search engine/big data - *Elasticsearch (ES)*
  - Ingest nodes – *Logstash/Beats*

- Abstraction layer between ingest modules and search engine, enables using ES for various monitoring applications → *Provide the proper communication of an ingest module with the ES through a common API*

- You don't need to rebuild the whole system when adding new features – just adapt your new plugin to the ES framework through API

- Additional notes:
  - *Kibana* can also run on top of different databases (e.g. *Prometheus*), dedicated for IoT metrics
  - *Elasticsearch* is more for logs search and processing – can also work with IoT metrics, but is less efficient, thus integration can be done on a different level



Tip: Have an integration possibility on many levels, to decide where to integrate / where things fit optimally!

Conclusions and Summary

Future – Beyond 5G

NEXT "should" be:

- Flexible, programmable, software-defined and cloud-enabled network…
- … highly heterogeneous, using multi-connectivity and multi-RAT concepts…
- … combined with various spectrum licensing and management schemes, utilizing wide range of bands (from below 1 GHz to up to/and beyond 100 GHz)……
- … optimized and tailored to specific-services and multi-tenant enabled…
- … with unified and hybrid management…
- … fully automated and self-learning.

It all comes down to – where to put the abstraction

How to Approach **NextG?**

- Hybrid and modular design for easy plug-in and ”plug-out”
- Use abstraction layers
- Use advanced sharing schemes: CBRS, ”NHN-like”, dynamic spectrum sharing, etc.
- Use open interfaces
- Allow 3rd party solutions
- Integrate what’s out there together with new solutions

NextG Approach – **Where To Start?**

Legacy Monolithic RANs

- Single network
- Closed interfaces
- Single vendor
- HW-based RAN
- Limited RAN-sharing

→

Open Networking in RAN

- Hybrid networks (integrated solutions)
- Open interfaces
- Different vendors and open initiatives (xRAN, vRAN, C-RAN, O-RAN, TIP, …)
- RAN virtualization
- Neutral-host networks, SCaaS

Some "Philosophical" Quotes

Is 5G the "last" generation? Two perspectives:

- *If we get 5G right there may not be a 6G.* (BT – Andy Sutton [1])
- *If it carries on like it is today, 5G will probably be the last generation of technology that rolls out because mobile operators just won't be profitable.* (Rakuten [2])

From uniformity to diversity:

- *In 5G, in other words, variety and diversity (of cells and their deployers) will replace uniformity.* (SCF [3])
- *The risk of diversity, however, is fragmentation.* (SCF [3])

[1] https://www.fiercewireless.com/special-report/europe-accelerates-push-toward-a-5g-wireless-future
[2] https://www.rcrwireless.com/20190911/5g/5g-lessons-reliance-jio-rakuten
[3] https://www.smallcellforum.org/blog/neutral-host-moves-to-the-top-of-scfs-agenda-as-it-proves-essential-to-5g-success/

So: GO **hybrid!**

NEXT?

Source: toyota

Let's talk:
5G, SD-WAN, Wireless, IoT, Proptech.

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