Anticipatory resource allocation in wireless networks

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Every success has its network

Bell Labs
Alcatel·Lucent

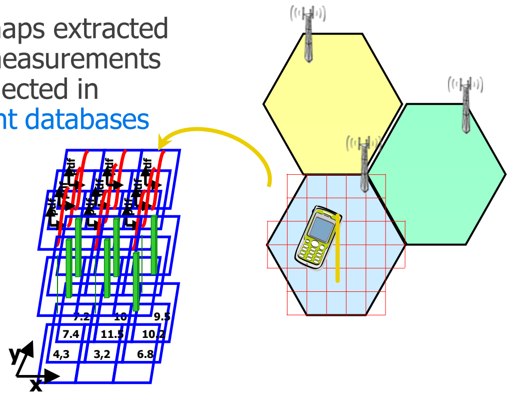
Agenda

1. Requirements in 5G networks
2. Anticipatory Optimization in 5G
3. Research challenges
4. Use cases
5. Conclusion

Requirements for 5G networks

- Data collection and analysis in 5G network will be different from today:
  - Increased quantity and quality of available data
    - e.g. UE measurements, location information
  - Map creators provide relevant, extracted data
    - spatially and temporally resolved network parameters e.g. spectral efficiency distribution, load
    - service requirements for every location and hour of the day e.g. service/traffic demand, QoS

Data maps extracted from measurements are collected in different databases

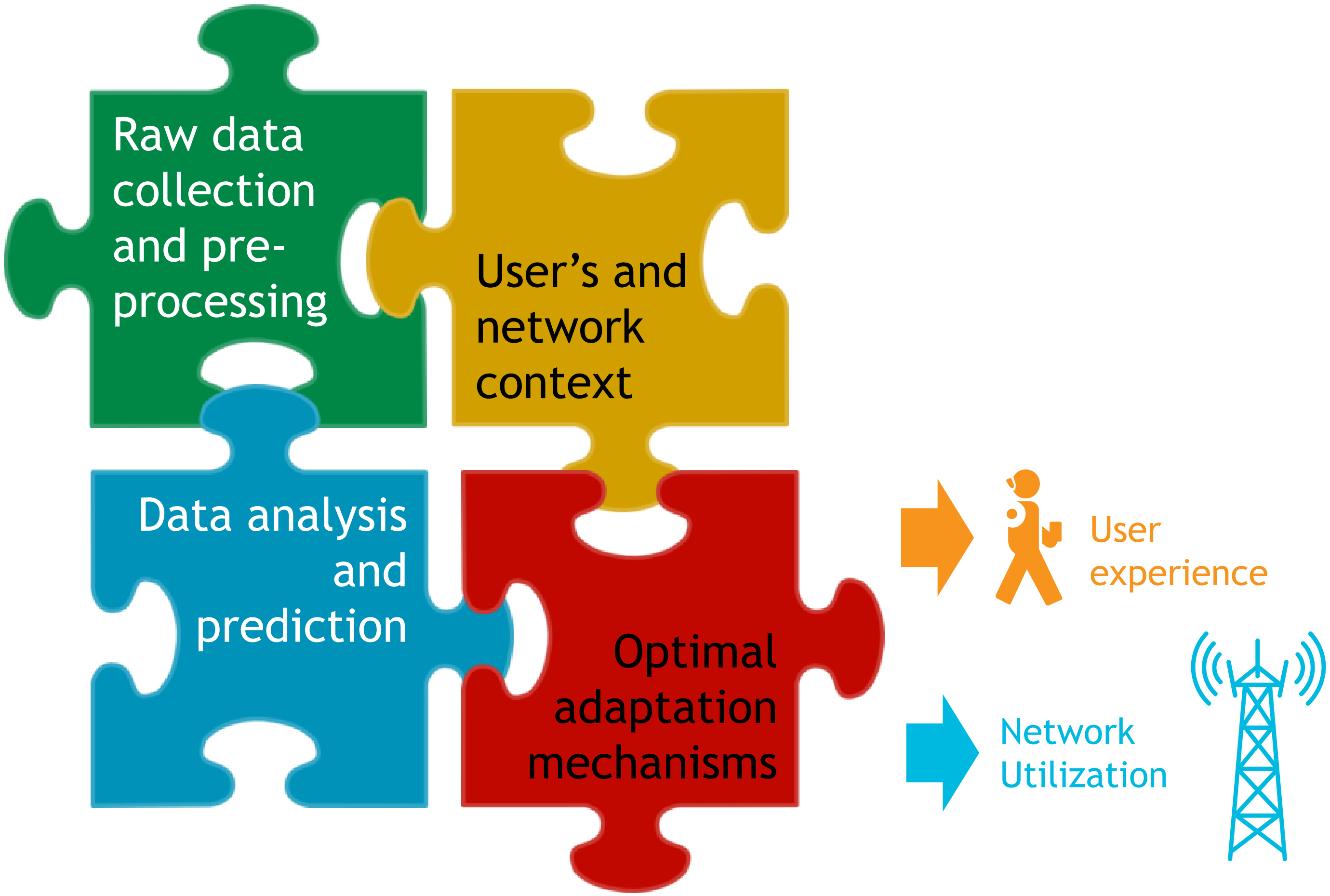


"The operator of the 5G system should be able to securely collect information that can enhance user experience and service experience via data analytics." [*NGMN 5G Initiative White Paper*]

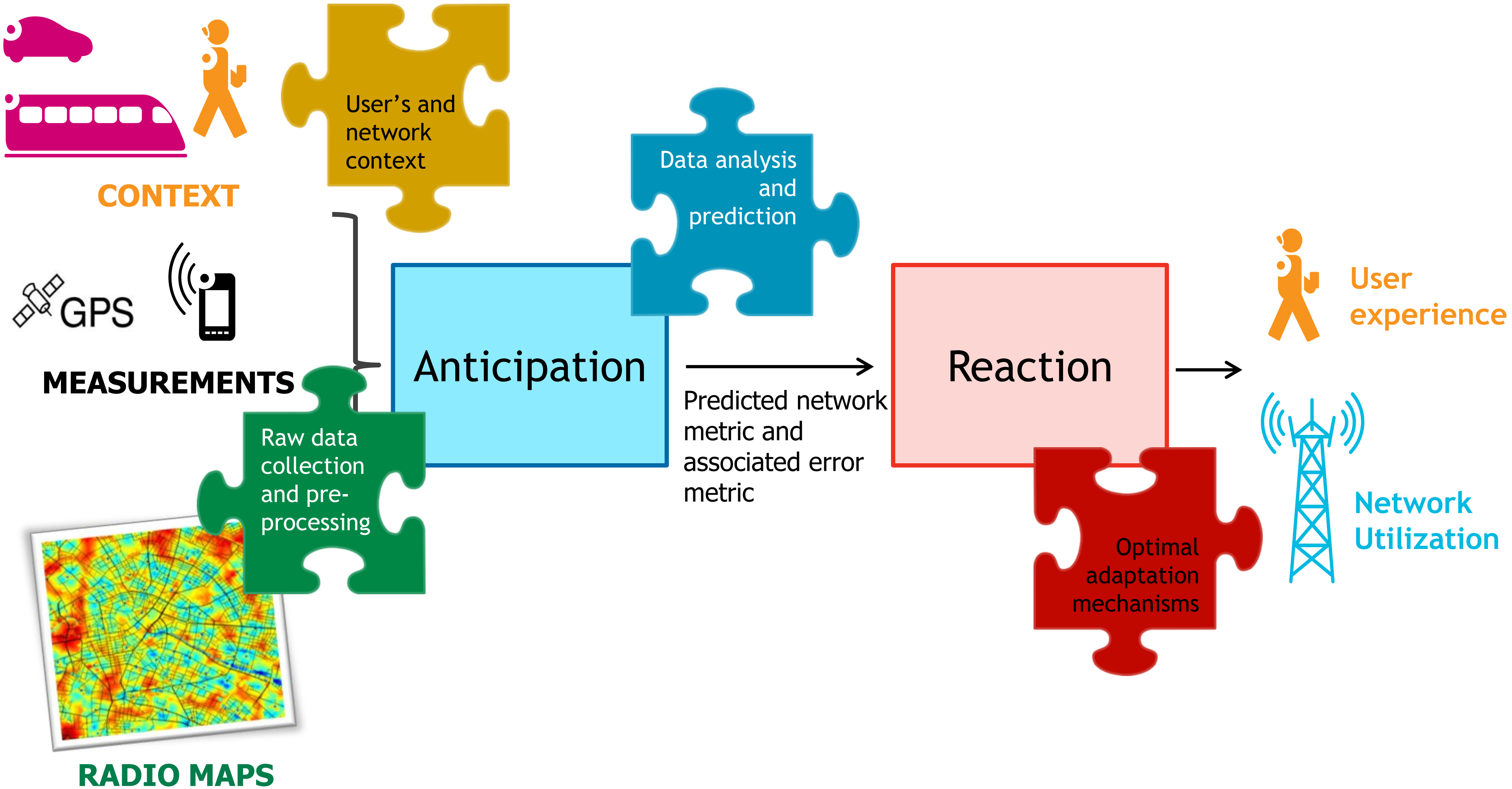
"The network cannot provide resources tailored to serve a wide range of devices and applications without context information that goes *significantly beyond* that available in 4G."
[4G Americas' Recommendations on 5G Requirements and Solutions]

- 5G will require high flexibility and fast re-configurability for, e.g.,
  - Provide tailored services to the users (based on user's requirements, context)
  - High data rate, very low latency services
  - Flexible Multi-RAT resource allocation (in time, frequency, space)

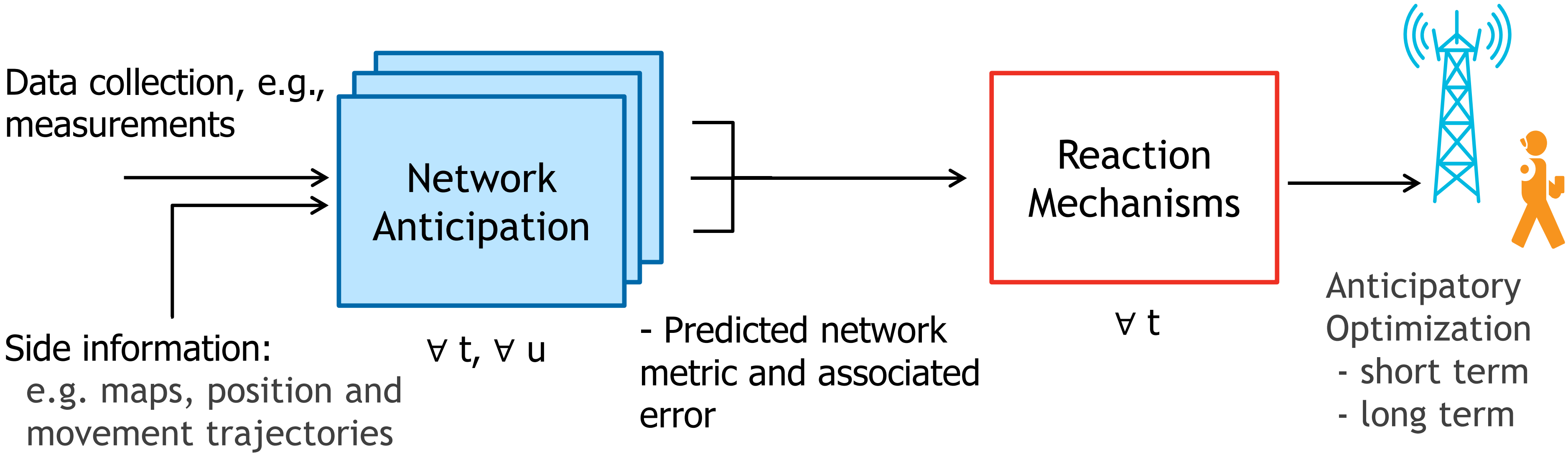
Anticipatory Optimization in 5G



Anticipatory Optimization in 5G



Research investigation field



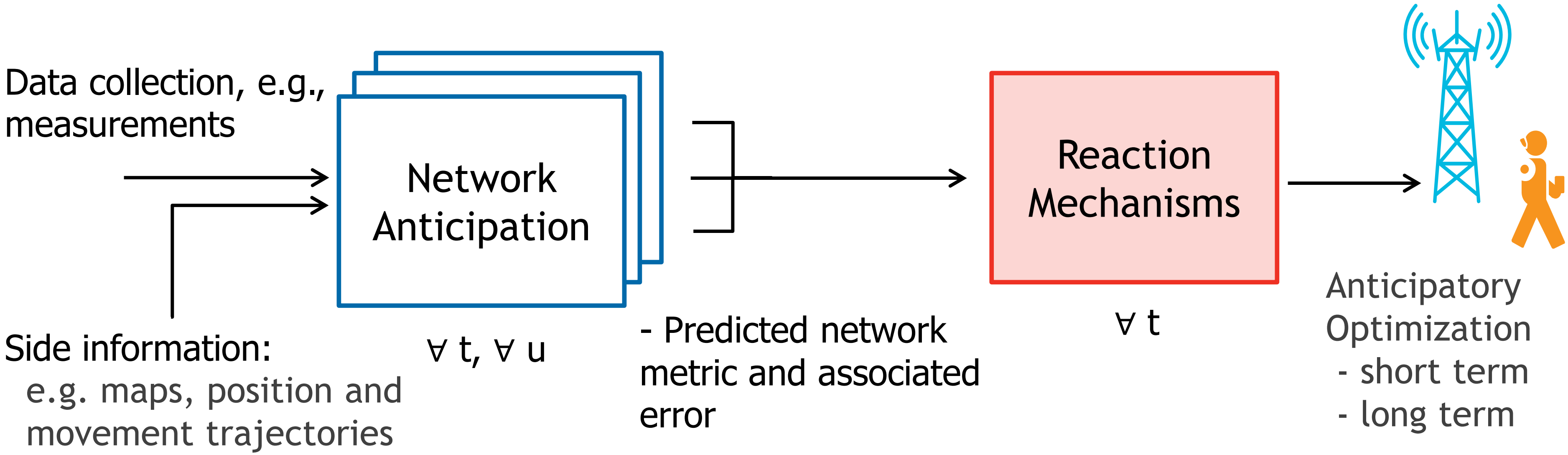
Network anticipation

- Investigate analytic methods for data analysis to model the network: accuracy vs. complexity
- Prediction techniques for assessing network parameters (e.g., expected interference, cell load) and user parameters (e.g., expected rate)

Challenges

- How to generate and update maps from raw measurements, considering e.g. different environments?
- How to provide computationally efficient learning/adaptive algorithms to estimate and predict upcoming network status?

Research investigation field



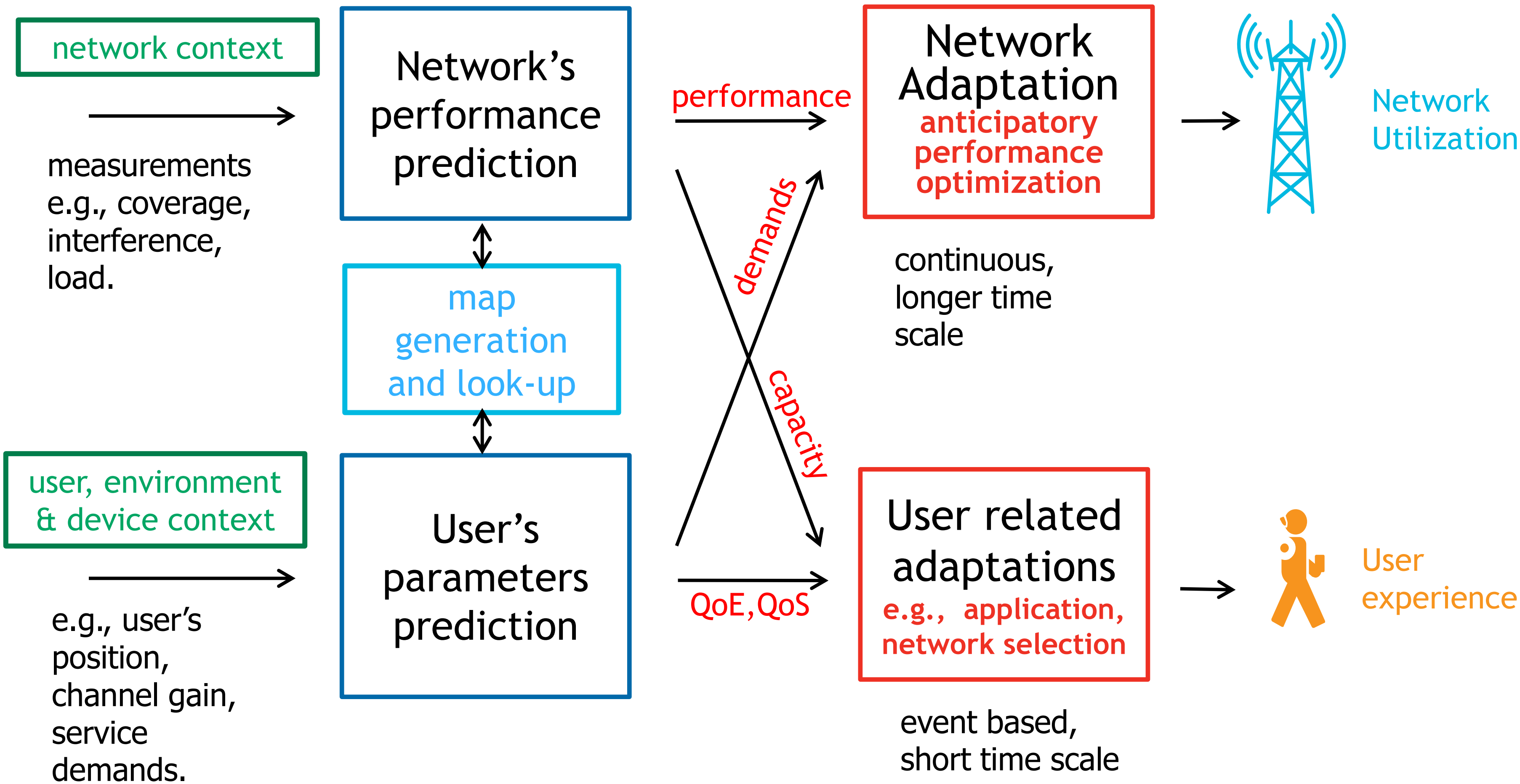
Reaction mechanisms

- Improved resource and management optimization techniques
- Infrastructure/resource sharing models across operators

Challenges

- Identifying the impact of using anticipatory information to different use cases (video quality adaptation, RRM, multi-RAT selection)
- Design of anticipatory optimization algorithms for the specific use cases

Network and User dependencies



Use case study: media content streaming

- **Media streams in mobile networks are subject to:**
  - Bandwidth fluctuation (e.g., due to user mobility)
  - Limited coverage (e.g., due to environment)
  - Congestion (e.g., in crowded areas)

- **Multimedia streams can exploit:**
  - Variable channel conditions and therefore achievable rate
  - Prediction of the future system state
  - Prediction of the user’s requirements
  - Possibility of content buffering

Use case study: media content streaming

- **Main idea: Opportunistic scheduling**
  - **Utilize channel proportional to its quality**
  - Assign fraction of channel resources $w_{j,t}$ to user j at time slot t
- At high channel state: Upload playout buffer by assigning high $w_{j,t}$
  - E.g., when user is close to eNB
- At poor channel state: Consume playout buffer by assigning low $w_{j,t}$
  - E.g., when user is at cell edge, in tunnel, or in overloaded cell

Conceptual benefit: Mobility compensates for poor coverage

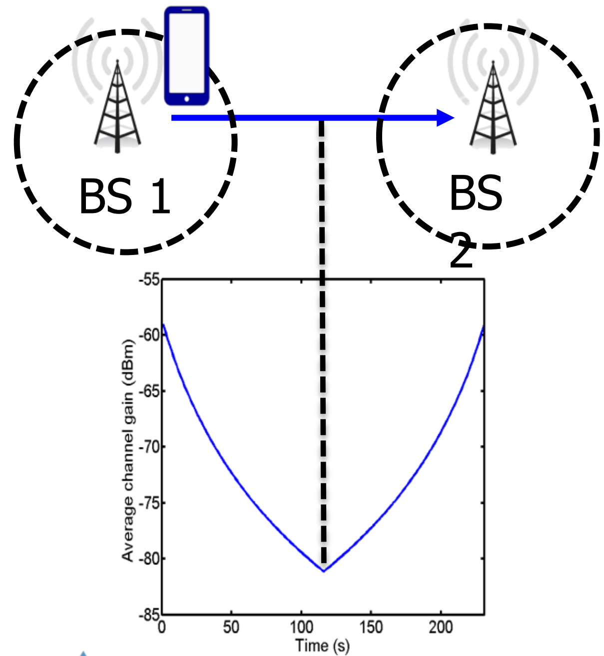
- In coverage hole: User *consumes* buffer since channel resources are "expensive", adds no further load to eventually highly loaded cell
- After leaving coverage hole: User *fills* buffer since channel resources are "cheap", prepares for next coverage hole

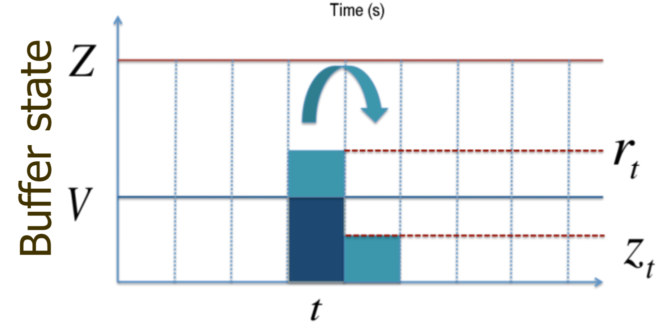
=> Using channel resources at high state is more likely

=> Spectral efficiency increases *while* avoiding buffer underruns

Proactive resource allocation for video streaming

- **Idea:** fill in the buffer when the radio condition is good and do not allocate resources to the users when this is too costly
- **Approach:** optimization problem where the future channel condition is incorporated in order to satisfy the demand of the video users (with zero delay) and minimize the consumption of resource.
- **Known parameters** (context):
  - Average future channel gain
  - User type: Video or best effort
  - Video bit rate requested by users
  - Maximum buffer size.
- **Results:** Scenario with 2 cells, multiple moving video users and large number of best effort users. Anticipative RRM saves up to 60% wireless channel resources depending on the maximum buffer size for the video users





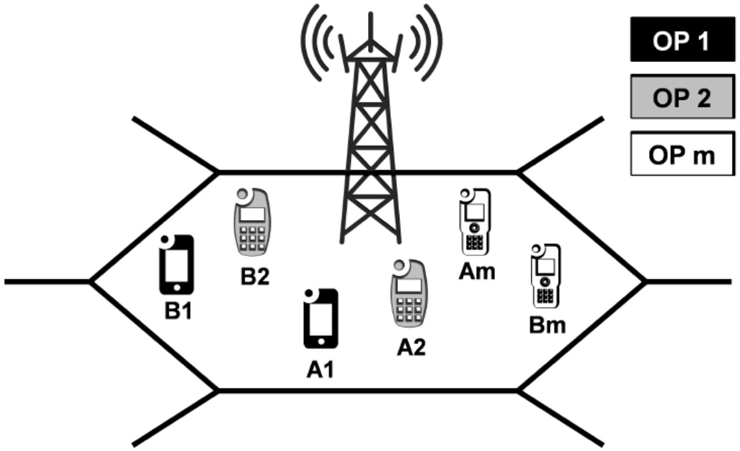
Stefan Valentin, "Anticipatory Resource Allocation for Wireless Video Streaming". Communication Systems (ICCS), 2014 IEEE International Conference on.

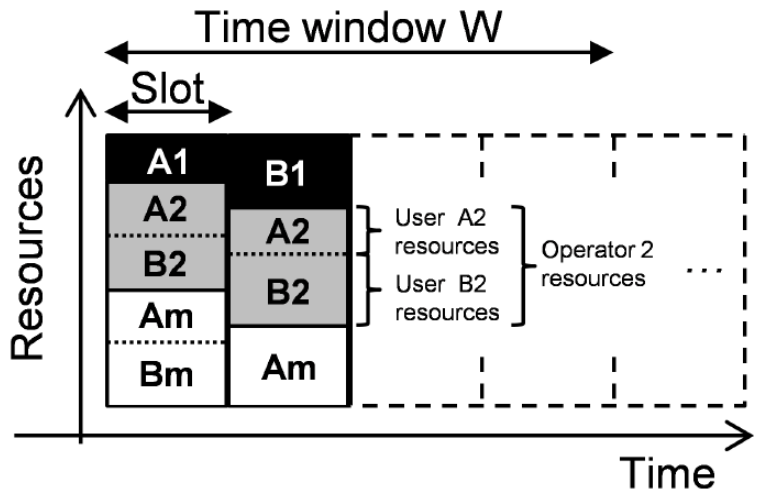
Use case study: multi-operator sharing

- We study the scheduler of a single Base Station (BS) that allocates wireless channel resources to users of multiple operators.
- At every time slot, the scheduler decides on the percentage of resources to allocate to the users of different operators.
- We assume that infrastructure provider and operators agree a priori on specific service level agreements, i.e., sharing guarantees. These are expressed with the triple:

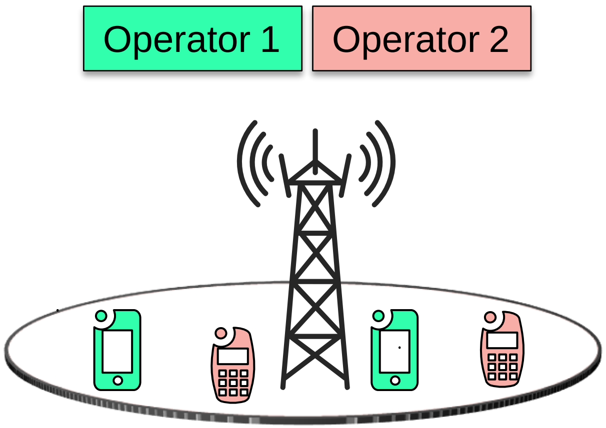
$$< \tilde{S}_m , \Delta, W >$$

that corresponds to *sharing ratio*, *maximum deviation* and *time window* within the deviation is allowed.

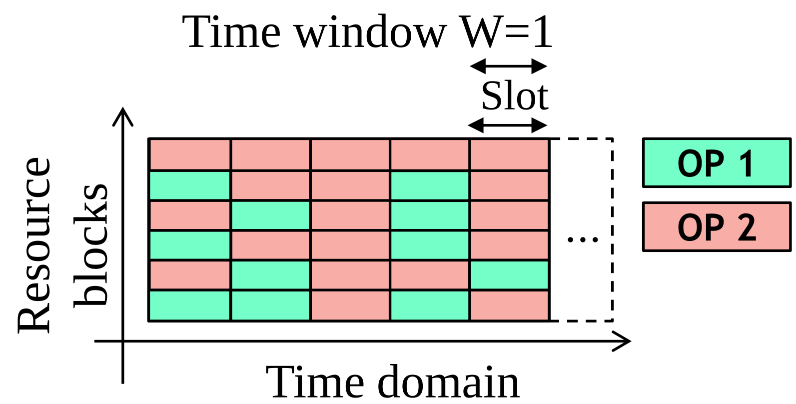




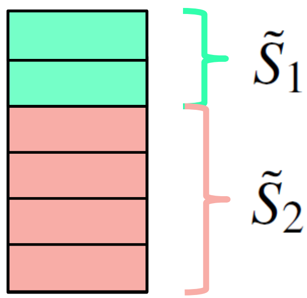
The 2-operator case: introducing the sharing guarantees

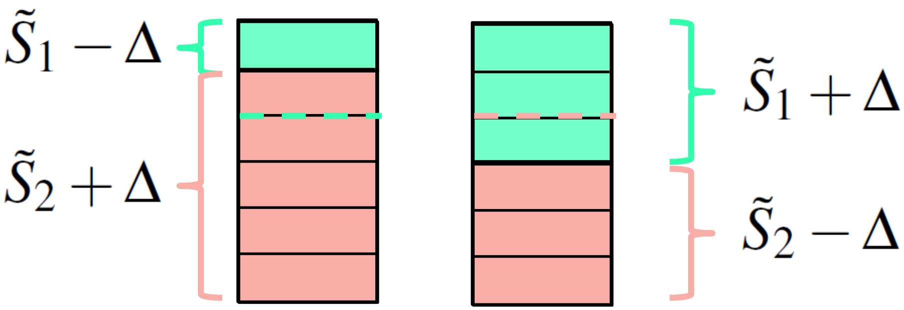


Operators agree on sharing ratios



On a short time scale, scheduler can deviate to optimize the use of resources





$\tilde{S}_m$: agreed sharing ratio

$s_m[n]$: instantaneous sharing ratio

Multi-Operator Scheduling Problem: Formulation

$$\begin{aligned}
\max_{\mathbf{x}} \quad & \sum_{n\in\mathcal{N}}\sum_{k\in\mathcal{K}} f(r_k[n], x_k[n]) & \\
\text{s.t.} \quad & \sum_{k\in\mathcal{K}} x_k[n] = 1 & \forall\, n \in \mathcal{N} \\
& \left|\left(\frac{1}{W}\sum_{i=n-W+1}^{n}\sum_{k\in\mathcal{K}_m} x_k[i]\right) - \tilde{S}_m\right| \le \Delta & \forall\, m \in \mathcal{M},\ \forall\, n \in \mathcal{N} \\
& x_k[n] \ge 0 & \forall\, k \in \mathcal{K},\ \forall\, n \in \mathcal{N}
\end{aligned}$$

PERFORMANCE EVALUATION

- Average aggregate spectral efficiency

$$R = \frac{1}{N}\frac{1}{|\mathcal{M}|}\sum_{k\in\mathcal{K}}\sum_{n\in\mathcal{N}} r_k[n]x_k[n]$$

- Fairness

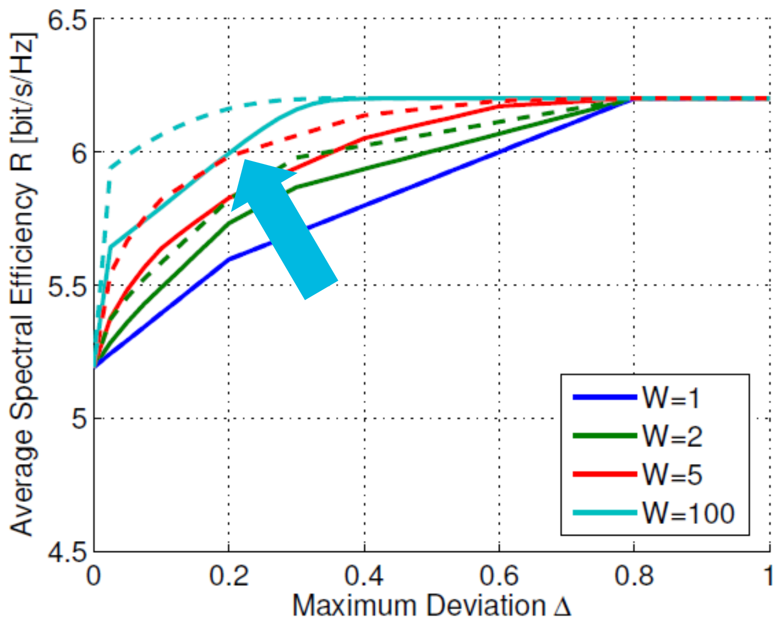
$$B_m = \frac{1}{N}\sum_{n=1}^{N}\frac{s_m[n]}{\tilde{S}_m} \qquad J = \frac{\left(\sum_{m\in\mathcal{M}} B_m\right)^2}{|\mathcal{M}|\cdot\sum_{m\in\mathcal{M}} B_m^2}$$

- The scheduler maximizes a utility function that depends on the spectral efficiency, e.g., Max-Rate/Proportional-Fair scheduler.
  - The sum of sharing ratios over all users has to be equal to 1 (complete use of resources)
  - Deviation of the moving W-average sharing ratio from the agree sharing ratio should be in the agreed maximum deviation
  - The utility function includes **information about future channels states**

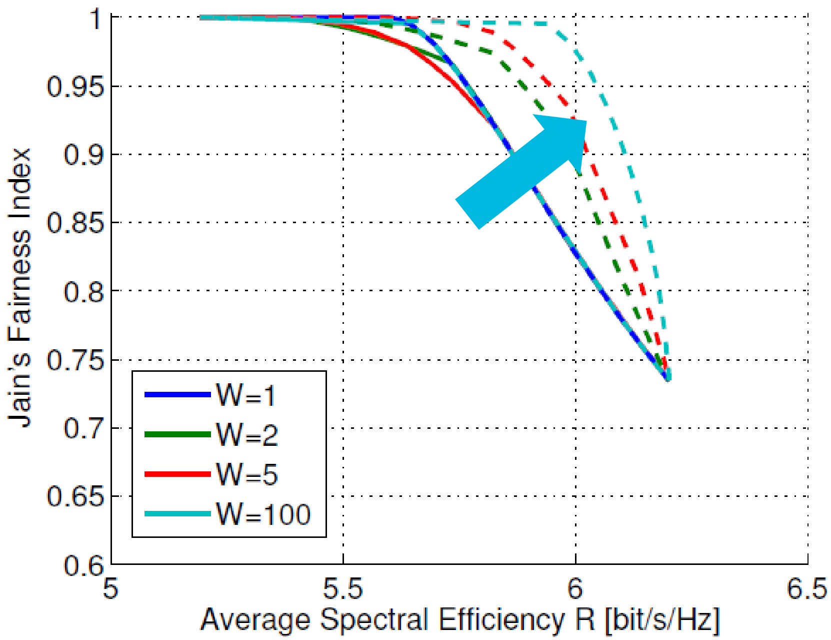
- Performance in terms of average aggregate spectral efficiency and fairness

Ilaria Malanchini, Stefan Valentin, Osman Aydin. "Wireless Resource Sharing for Multiple Operators: Generalization, Fairness, and the Value of Prediction," submitted.

Simulation results: coupled effect of Δ and W



(b) $\tilde{S}_1 = 0.2, \tilde{S}_2 = 0.8, \tilde{\Delta} = 0.8$



(b) $\tilde{S}_1 = 0.2, \tilde{S}_2 = 0.8$

Solid lines report results for Multi Operator Scheduler without anticipation
Dotted lines report results for the **Anticipatory Multi-Operator Scheduler**

Conclusion

- 5G networks will be designed for supporting knowledge acquisition and analysis
- Anticipatory optimization will improve network utilization and user experience
- Resource allocation is one of the field that can take more benefits from *anticipating the future*
- Past research has mainly focused on media content streaming optimization and multi-operator scheduling
- Open research questions include:
  - What are other relevant use cases?
  - How to predict the future channel gains of a specific user?

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