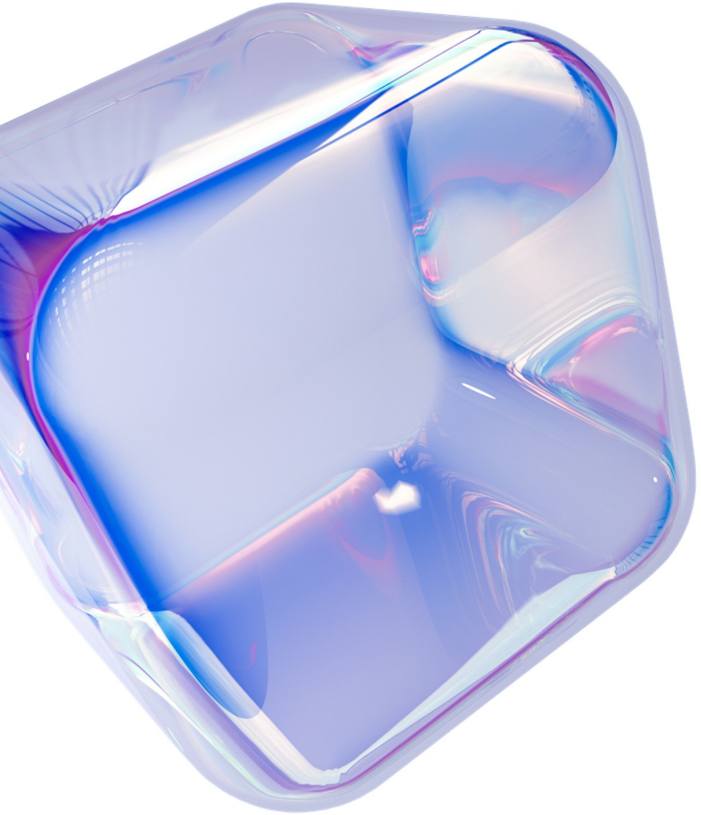

Spectrum Allocation as Concurrent Programming

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PTC'23
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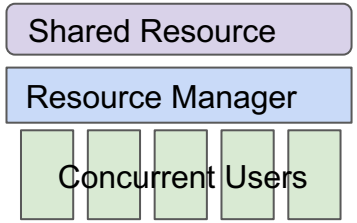
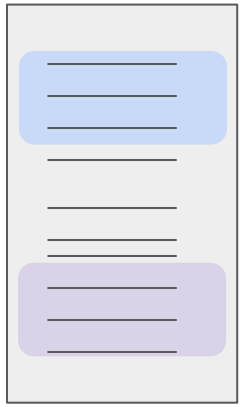
Outline

1. We can use the “metaphor” of concurrent programming to describe an important problem addressed within spectrum-management.
    1. Explain the intuitions that underlie this approach
    2. Explain the Rely-Guarantee framework for verifying specifications
2. Discuss a case-study : 5G-vs-RadioAltimeters where this approach may be applied.
3. Open Discussion

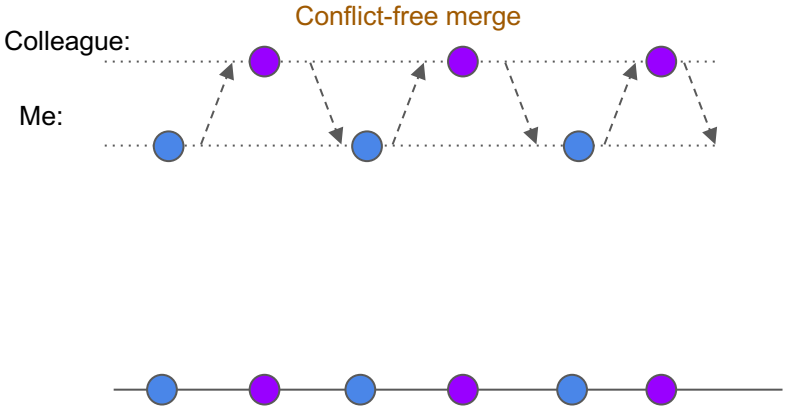
Collaborative Document-Editing

Collaborative Document-Editing (v1.X)





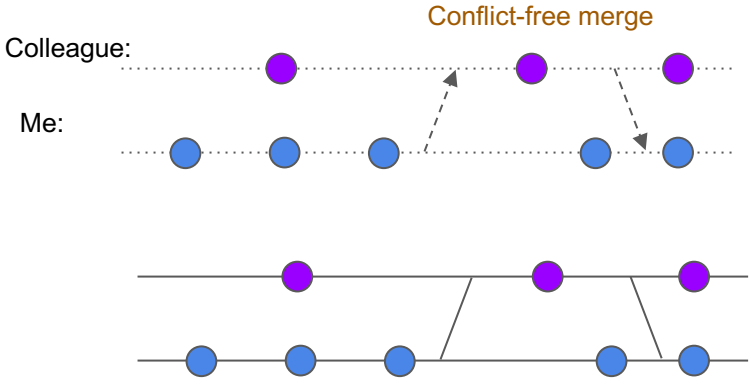
Time-scheduling



Event-Graph (Total-order)

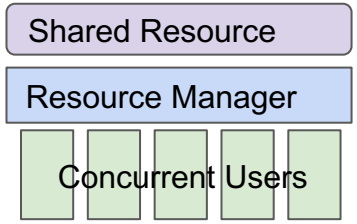
Region-scheduling

Apriori Region Allocation



Event-Graph (Partial-order)

Comparison of Spectrum Management Strategies



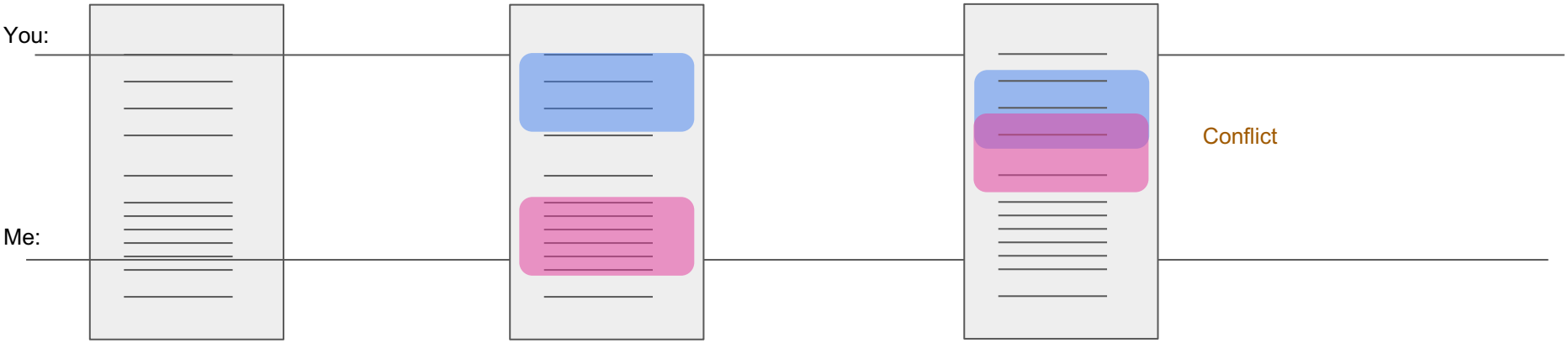
Region-Scheduling	Time-Scheduling (Spectrum Sharing in CBRS)	Time-Scheduling (Unlicensed)
Interference-avoidant operation	Interference-avoidant operation	Interference-avoidant operation
EM-Spectrum	EM-Spectrum	EM-Spectrum
Spectrum Allocation	**Central Server: SAS/AFC**	**Decentralized MAC Algos**
Radio Services	Radio Operators/Devices	Radio Devices

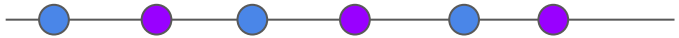
What do we gain from such a comparison?

Opportunity for interdisciplinary research: interference management.

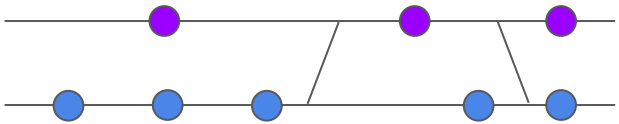
The spectrum-management community might benefit from exploring strategies for interference-management as developed within the concurrent programming community.

Collaborative Document-Editing (v2.0) : Google Docs





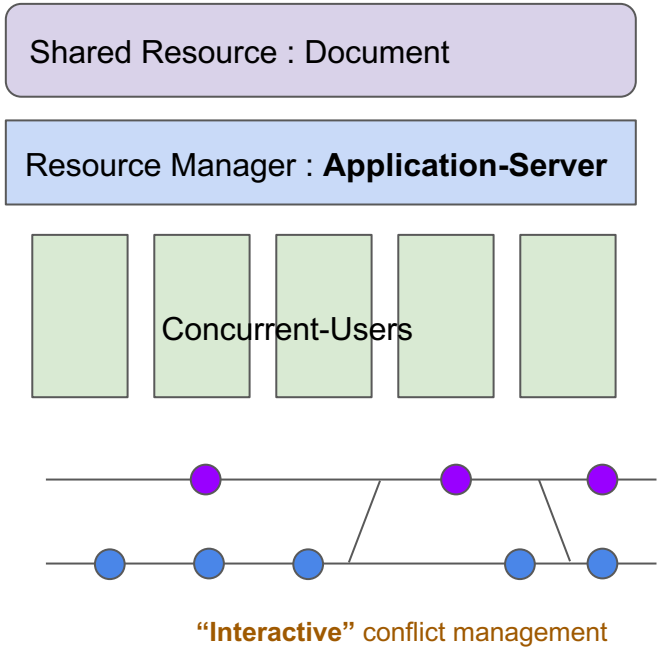
Conflict-free merge



What do you do during a conflict?

Collaborative Document-Editing (v2.0) : Google Docs

How does Google docs permit concurrent editing?



“Interactive” conflict management

Centralized Server :

1. Helps concurrent users identify conflicts as it happens.
2. Concurrent-users decide how to coordinate edits using side-channel.

Collaborative Document-Editing : What next?

Disadvantages of Google Docs:

1. Interactive conflict-management : Can this be automated?
2. Centralized server : Can we permit decentralized control?

Collaborative Document-Editing (3.0) : MRDTs

Mergeable - Replicated Data Types (MRDTs)

RESEARCH-ARTICLE OPEN ACCESS

AddThis

RunTime-assisted convergence in replicated data types

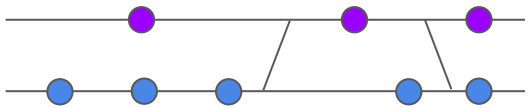
Authors: Gowtham Kaki, Prasanth Prahladan, Nicholas V. Lewchenko Authors Info & Claims

PLDI 2022: Proceedings of the 43rd ACM SIGPLAN International Conference on Programming Language Design and Implementation • June 2022 • Pages 364–378 • https://doi-org.colorado.idm.oclc.org/10.1145/3519939.3523724

Published: 09 June 2022 Publication History

Collaborative Document-Editing (3.0) : **MRDTs**

- Restrict the “geometry” of the Event-Graph
  - New Computational-model
  - Directed Acyclic Graph (DAGs)
  - Two-way ”merges”
  - Well-defined API-calls



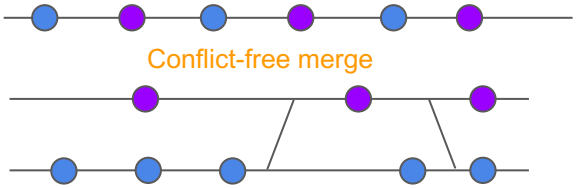
It is possible to achieve low-latency concurrent editing of a document across geographically distributed users while permitting custom-defined conflicts and guaranteeing convergence.

Evolution of Collaborative Document-Editing

Shared Resource
Resource Manager
Concurrent Users

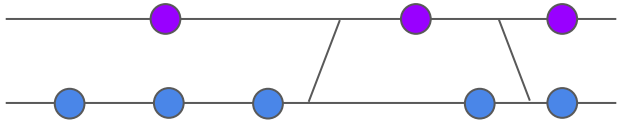
Resource-centric

Time/Region-Scheduling **(1.x)**



Document
Scheduler
Users
(Sequential/Concurrent)

Google Docs **(2.0)**

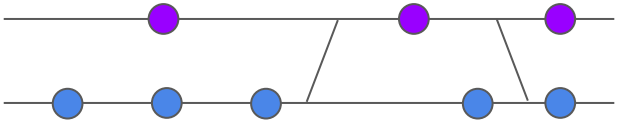


Interactive conflict management

Document
Application-Server
(Control + Data Layer)

Operation-centric

MRDTs **(3.0)**
Mergeable Replicated Data Types



automated conflict management
Custom-defined "**permissible**" conflicts

Document
Run-Time Engine
(Control Layer)

Research Question

How can we develop a similar operation-centric methodology within spectrum-management?

Why is this important?

FCC Launches Proceeding on Promoting Receiver Performance

Full Title: Promoting Efficient Use of Spectrum through Improved Receiver Interference Immunity Performance
Document Type(s): Notice of Inquiry
Bureau(s): Engineering & Technology

Description:
The Commission takes a fresh look at the role of receiver performance in our spectrum management responsibilities, with the goal of facilitating new opportunities for use of our nation's spectrum resources.

DA/FCC #: FCC-22-29
Docket/RM: 22-137
Federal Register Citation(s): 87 FR 29248 (05/13/2022)

Document Dates

Released On: Apr 21, 2022
Adopted On: Apr 21, 2022
Issued On: Apr 21, 2022

Tags:
Devices, Engineering & Technology

The Problem : “Incomplete” Specification

In particular, “reception” is not incorporated into the calculus.

Receivers operating in one band are not immune to radio energy entirely contained within adjacent or nearby bands.

Challenges arise due to:

1. Lack of information of the neighbour’s system specification
2. Externalities :
    a. costs borne by one entity, benefits reaped primarily by the other.
3. Changes in status-quo due to re-allocation
    a. Re-allocation of spectrum to different use, leads to change in RF-environment, which was considered at the time of design/deployment of neighbouring bands.

Two approaches to address the problem of Rx IX-immunity

1. Specify requirements on **performance of the equipment**
    a. Tx and Rx equipment performance standards/mandates
2. Specify the **RF environment** in which the device is expected to operate.
    a. Interference limits/Harm-claims threshold

The FCC's current rules are framed almost entirely in terms of performance requirements on equipment. There are only a few cases where the FCC has adopted Environment rules.

In search of a “complete specification” …

1. How do we know that incorporating “receiver-equipment specification” or “environment-specification” will be sufficient?
2. Will this help develop a specification that is “future-proof” ?

Our proposal:

A formal (“mathematical”) framework that has been tried and tested over decades to derive a “complete and verifiable” specification for radio-services.

Rely-Guarantee Framework for Verification

a) $p1 = p2 = p$

b) $R1 = R \vee G2$

c) $R2 = R \vee G1$

d) $G = G1 \vee G2$

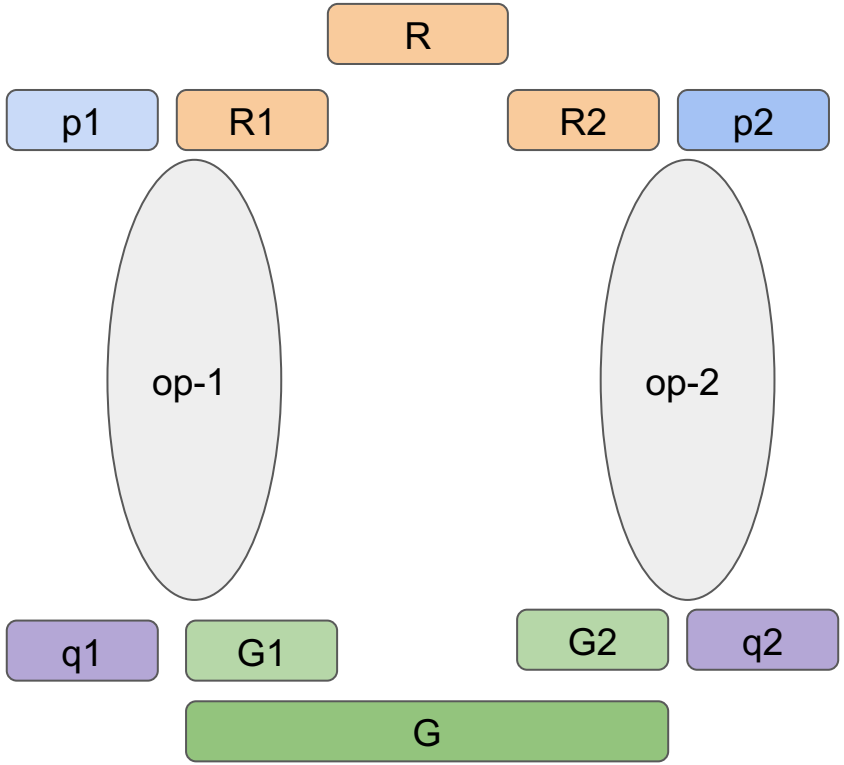
e) $Q = q1 \wedge q2$

Pre-Condition (p)

Post-Condition (q)

Rely-Contract (R)

Guarantee-Contract (G)



Rely Condition :

- Specifies “permissible behaviours” of **others**

Guarantee Condition:

- Specifies “permissible behaviour” of **self**

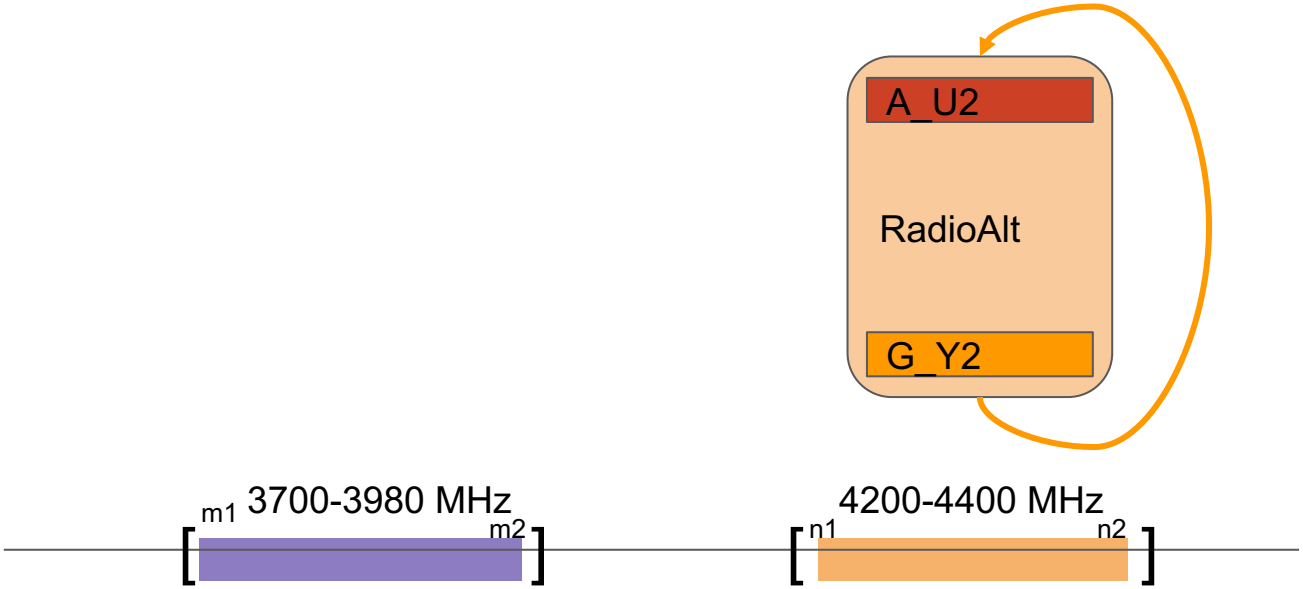
Case Study via “illustrations”: 5G -vs- Radio Altimeters

We shall examine a scenario where we can apply

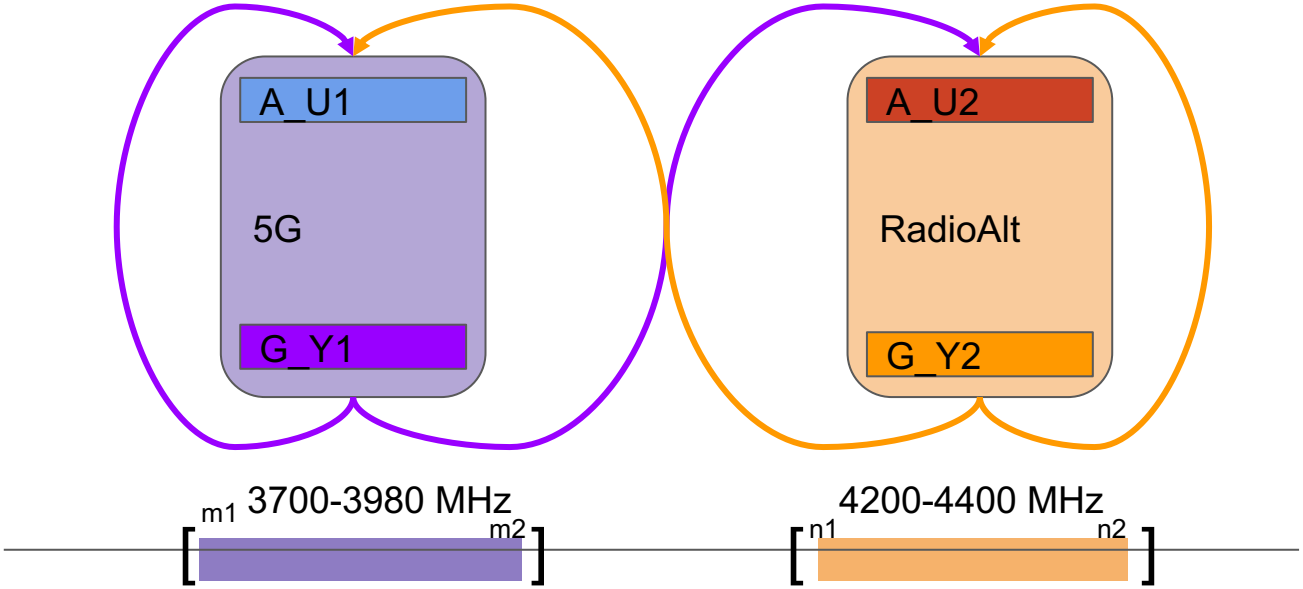
the Rely-Guarantee-framework

to reason about an issue with existing service-specification.

Case study : 5G -vs- RadioAltimeters



Case study : 5G -vs- RadioAltimeters



Rely-Contract of RadioAltimeter

Expectation:
Below -100dBm
(pretty silent)

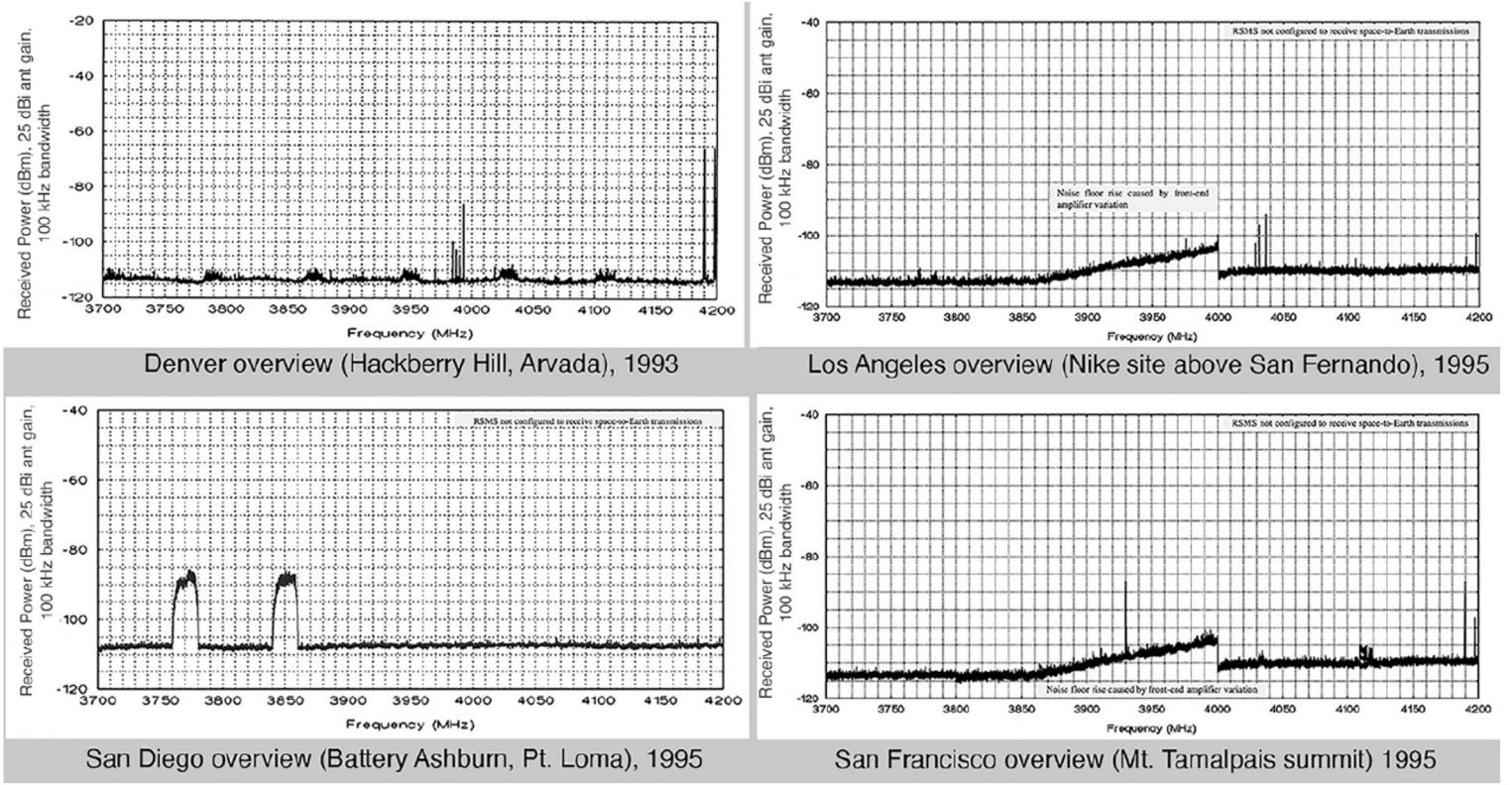


Figure 4. Mid-1990s spectrum occupancy scans of the 3700–4200 MHz band in four major US metropolitan areas, showing the historically quiet environment of that band in the US.

Guarantee Contract of 5G Radio

Reality:
Around -10dBm
(very noisy)

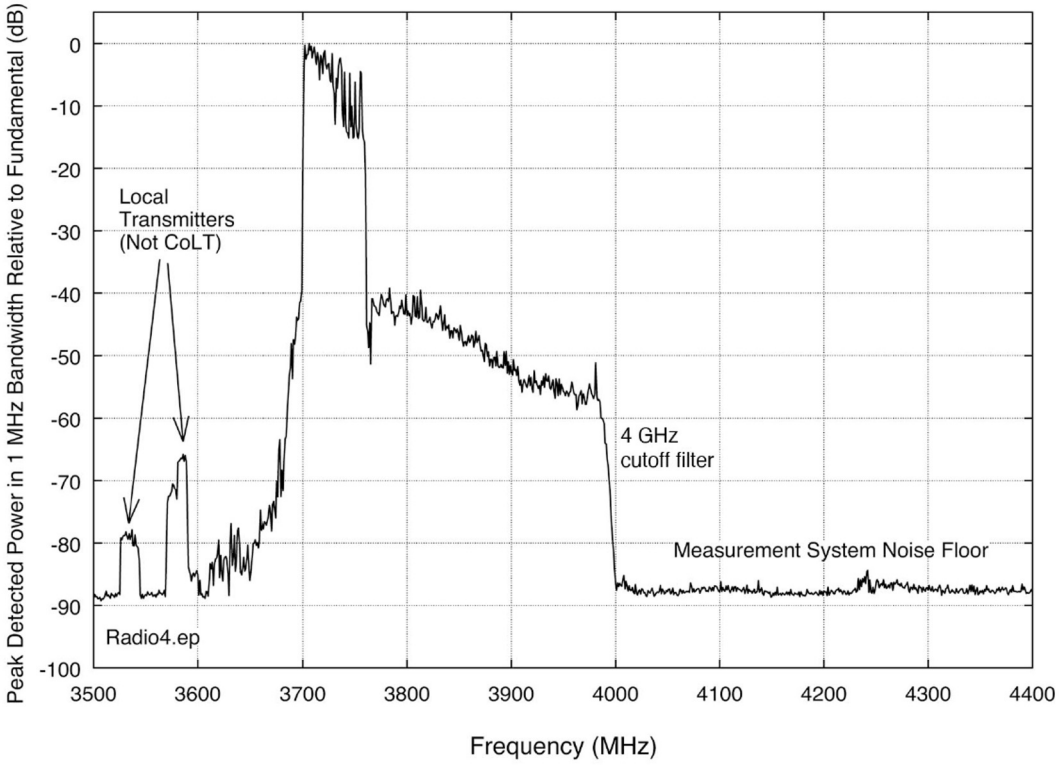
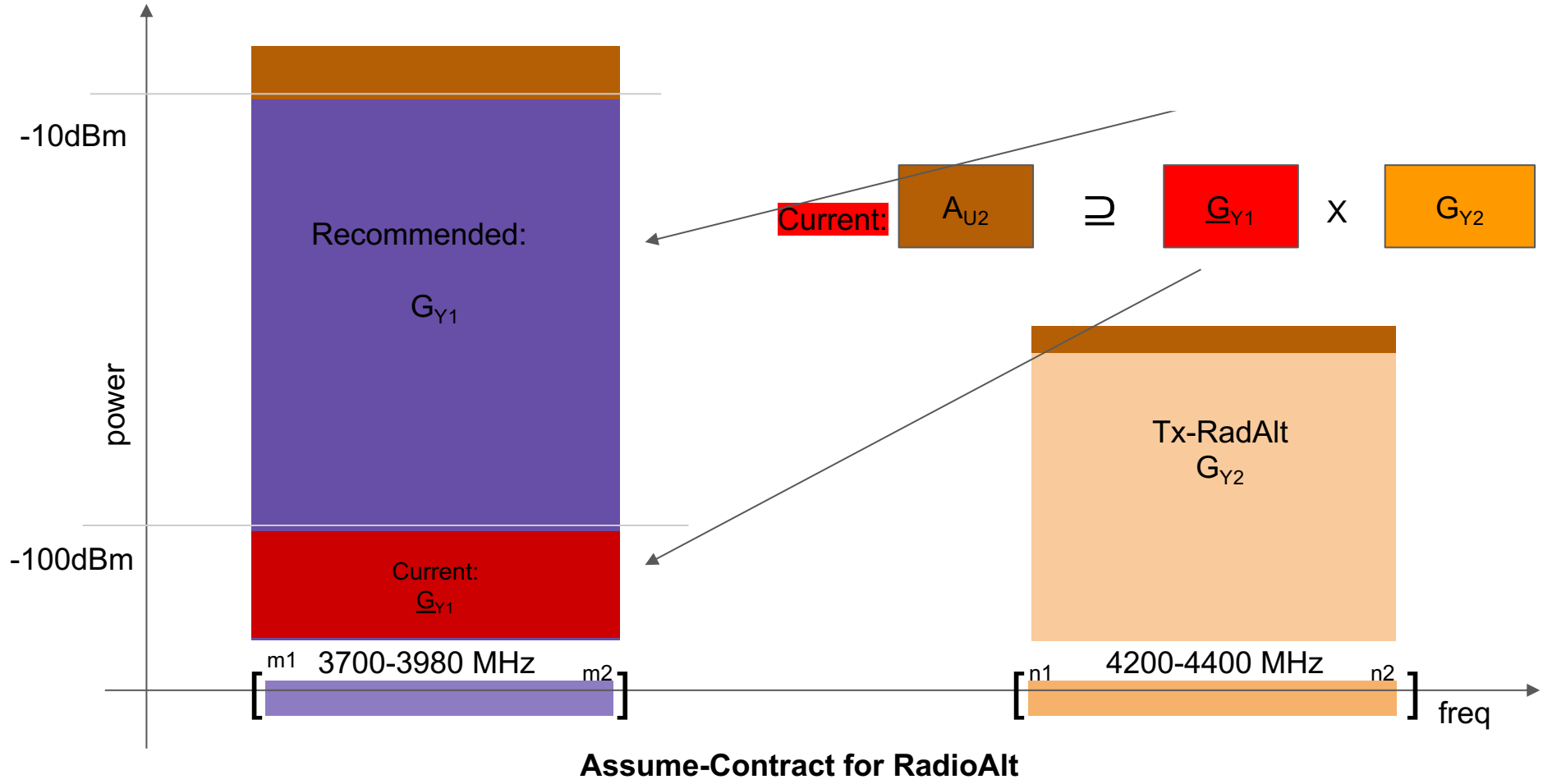
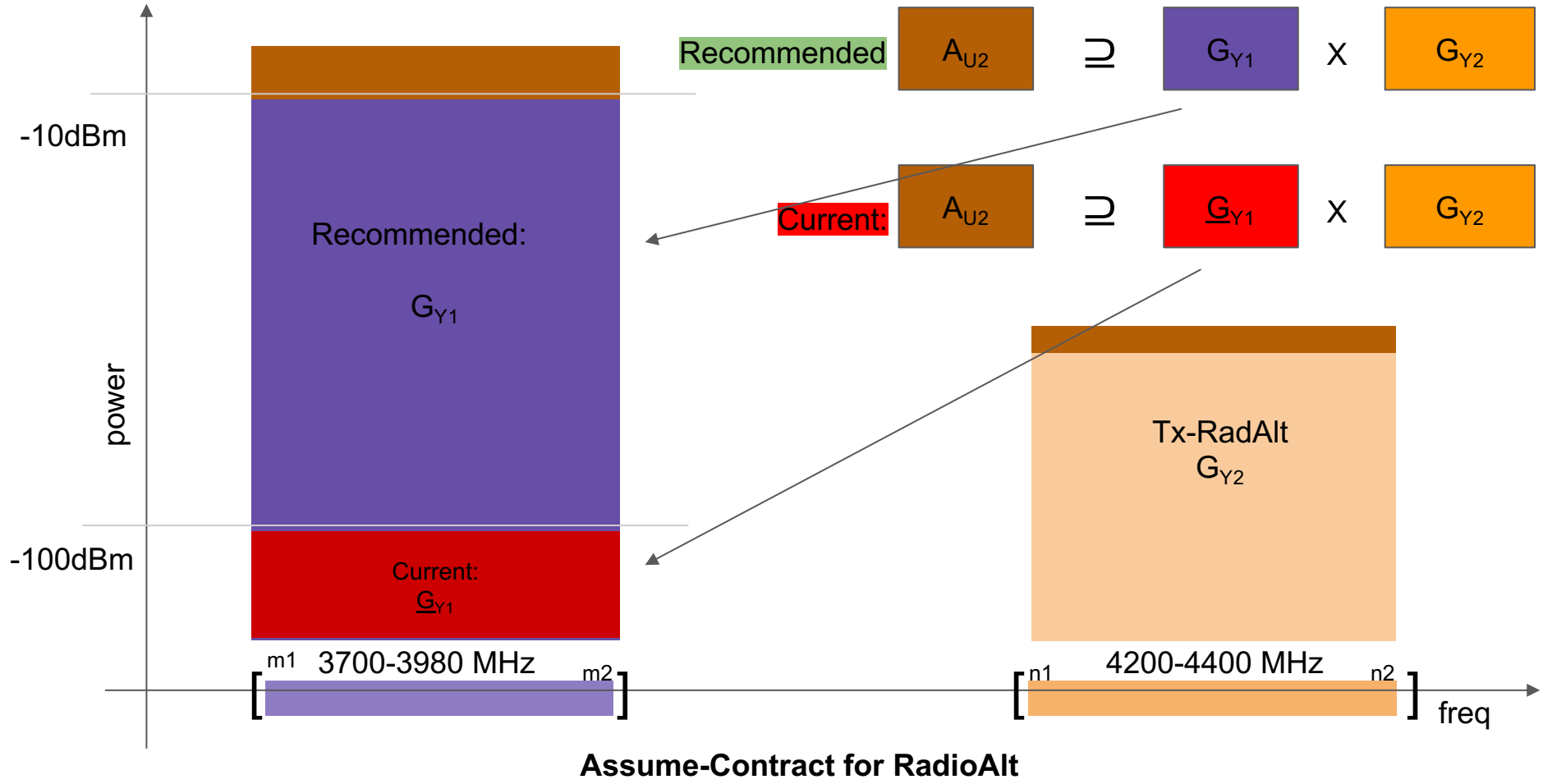


Figure 48. Measured emission spectrum of 5G base station transmitter Radio 4.



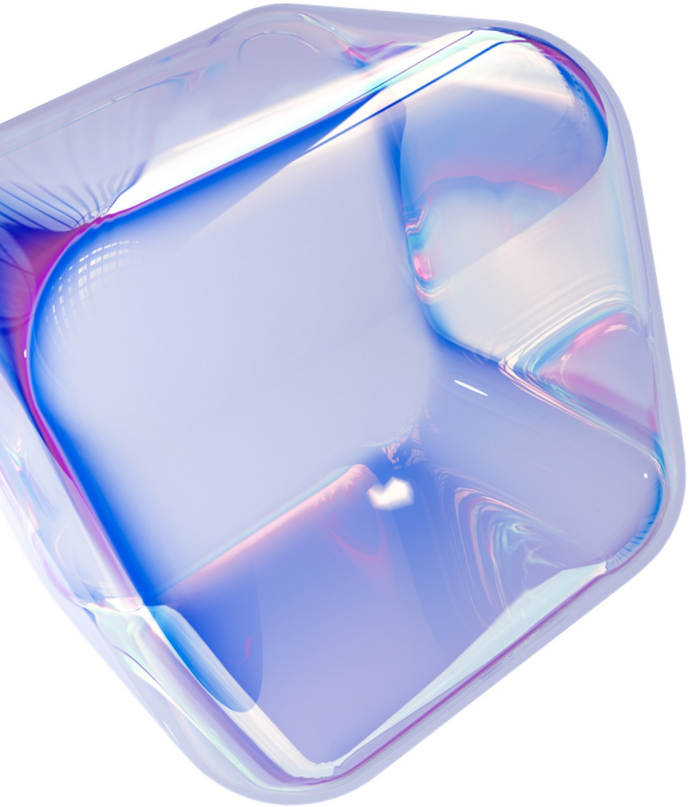
Assume-Contract for RadioAlt



Assume-Contract for RadioAlt

Open Discussion

1. What does the community think is important to develop a “complete specification”?
2. How should we compare different specifications?



Thank You

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