5G Spectrum Utilization and Spectrum Management

Meet 5G 1000x Traffic Requirement

Available Spectrum X **Spectrum efficiency** X **Network density** = **Traffic capacity**

- Higher frequency:
- Sub 6GHz,
- 3.5GHz, 4.9GHz
- Per carrier bandwidth >=100MHz

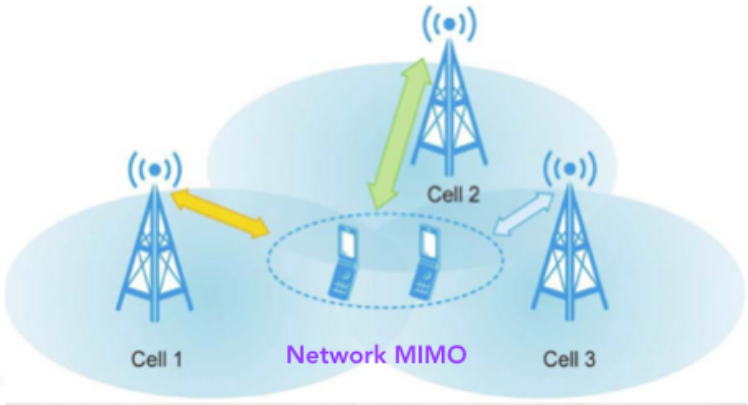
Shannon's Theorem

$C = B * log_2(1+ S/N)$

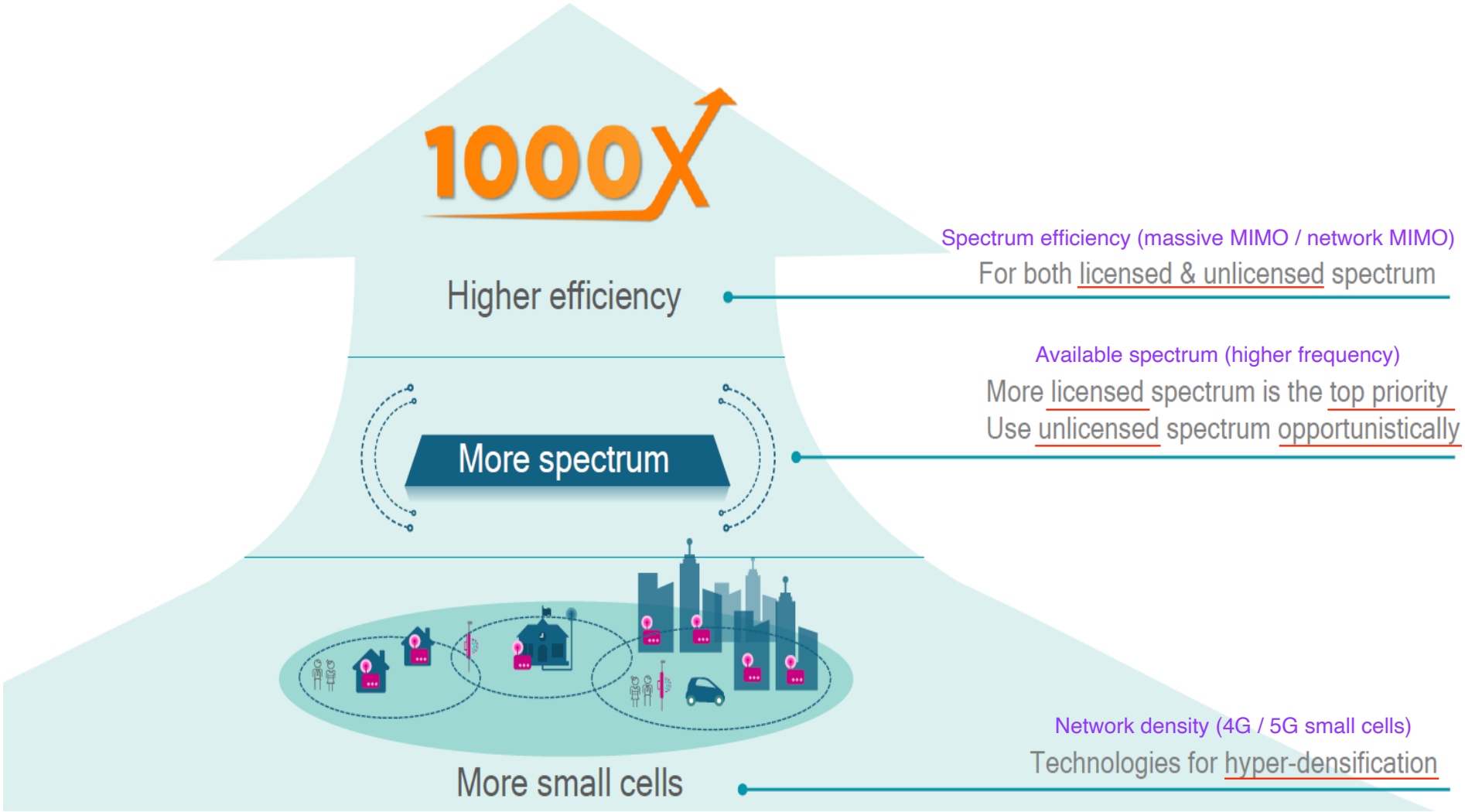
- Massive MIMO:
- Marco Base station, Antenna number >128
- High end small cell, Antenna number > 16

- Network MIMO:
- User centric,
- Multi-cell coordination, Coordinated small cell>=8

- 4G standalone small cell
- 4G virtualized small cell
- 5G stand alone small cell
- 5G virtualized small cell



Spectrum, Efficiency, Density



Using All Available Spectrum Types and Bands

Licensed spectrum

Exclusive use

Over 40 bands globally for LTE, remains the industry's top priority

Shared spectrum

New shared spectrum paradigms

Example: 2.3 GHz Europe / 3.5 GHz USA

Unlicensed spectrum

Shared use

Example: 2.4 GHz / 5-7 GHz / 57-71 GHz global

e.g. CBRS

e.g. MulteFire

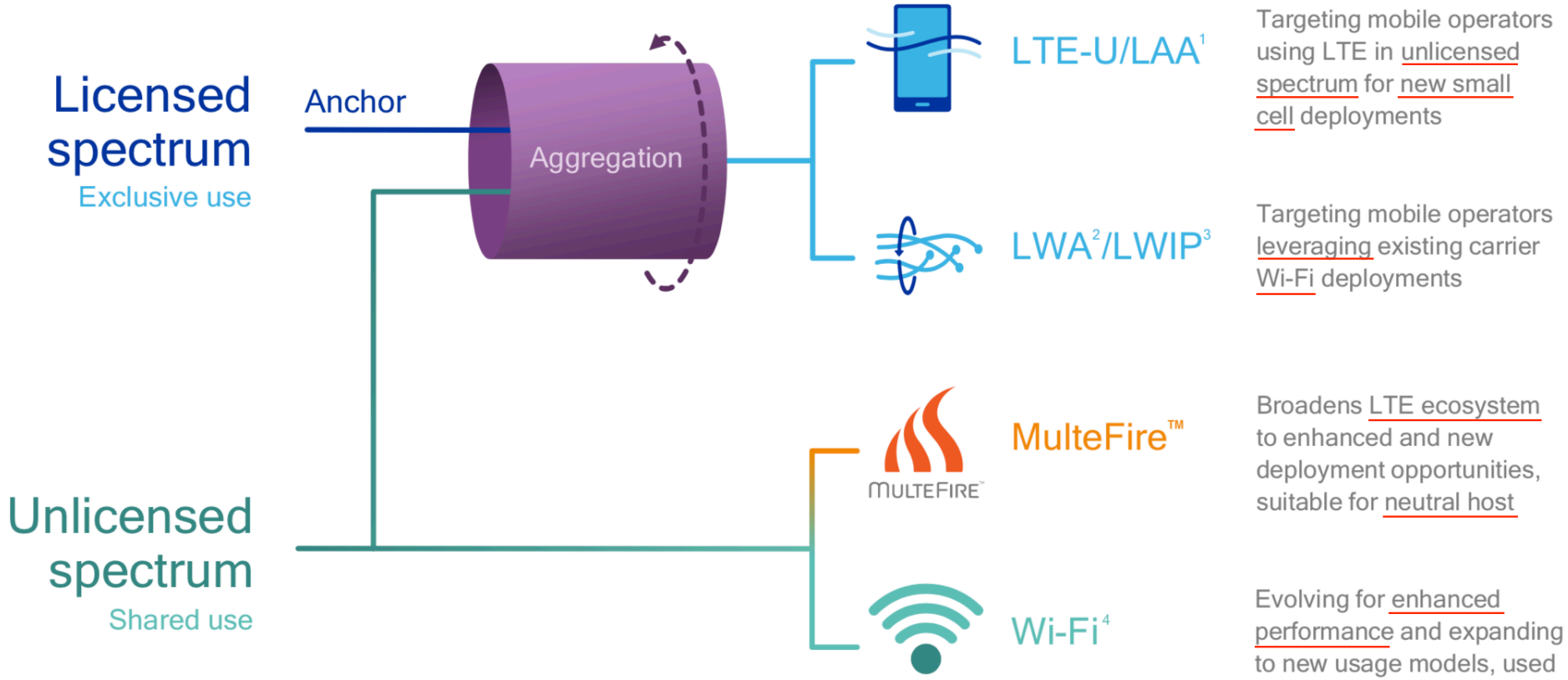
- **Citizens Broadband Radio Service (CBRS)** [USA]
  - A 150 MHz wide broadcast band of the 3.5 GHz band (3550 MHz to 3700 MHz)
  - Wireless carriers using CBRS might be able to deploy 5G mobile networks without having to acquire spectrum licenses

5G

Country	Low-band	Mid-band	mmWave bands
Brazil	---	3.4-3.6GHz	26, 40, 66-71GHz
China*		2.515-2.675GHz 3.5-3.6GHz 4.8-4.9GHz	24.75–27.5GHz 37– 42.5 GHz
EU-28	700MHz	1.4 GHz; 2.0 GHz; 3.4-3.8GHz	26-28GHz
India	---	3.6-4.2GHz 4.4-4.9GHz	28GHz
Japan	---	3.6-4.2GHz 4.4-4.9GHz	28GHz
Mexico	600MHz	---	26, 33, 37GHz
Russia	---	4.4-4.5GHz 4.8-4.9GHz	26, 40, 66-71GHz
South Korea	---	3.4-3.7GHz	26-28GHz
UAE	---	1.4, 3.3-3.8GHz	26GHz
United States	600MHz	2.6GHz	24, 28, 37, 39, 47, 64-71GHz

Source: Compiled from GSMA-TMG (2018, Figure 9, p. 14) with updates by authors.

Making Best Use of Shared / Unlicensed Spectrum



LTE-U：**LTE-U**nlicensed，**LAA**：**L**icensed **A**ssisted **A**ccess

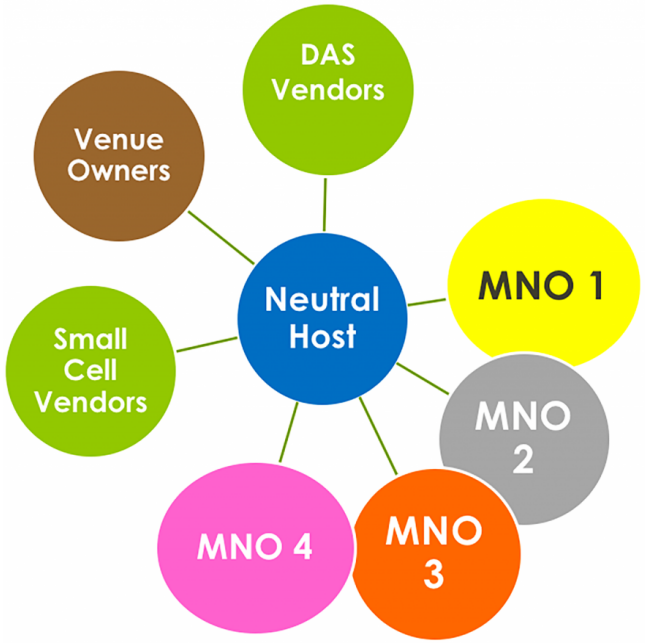
LWA：**L**TE-**W**LAN **A**ggregation，**LWIP**：**L**TE **W**LAN Radio Level Integration with **IP**sec Tunnel

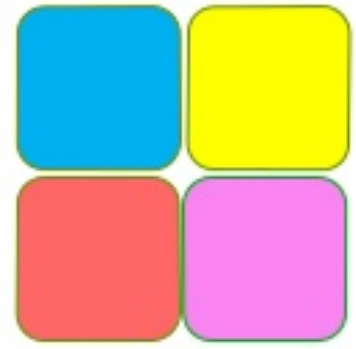
MulteFire

— An LTE-based technology that operates standalone in unlicensed and shared spectrum, including the global 5 GHz band

— Supports Listen-Before-Talk (LBT) for fair co-existence with Wi-Fi and other technologies operating in the same spectrum

- **Note：Small cell and neutral host**
  - **Small cell**
    - A cost effective solution for operators with network coverage and capacity issues
    - However, the single-operator nature of small cell makes the solution less efficient especially for enterprise and venue deployments which tend to have multi-operator environments
  - **Neutral host**
    - A network operated by a single company where resources are being shared by multiple Mobile Network Operators (MNOs) and Mobile Virtual Network Operators (MVNOs) to achieve a cost reduction and multi-operator environment for both operators and enterprise end customers
    - Also refer to the special case of network sharing through the use of the same small cell equipment with the capability of hosting multiple RANs





Cost to deploy 4 separate small cell networks by MNOs

Cost to deploy neutral host shared small cell network

Cost reduction passed to MNOs

LTE-U and LAA Part of Same Evolution

LTE-U
Time to market for certain regions: USA, Korea, India

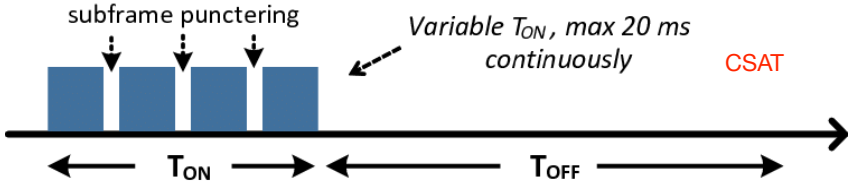
Based on 3GPP R12
- Supplemental downlink (SDL) to boost downlink
- Dynamic channel selection to avoid Wi-Fi and adaptive duty cycle (CSAT) to fairly coexist
- Support for migration to LAA

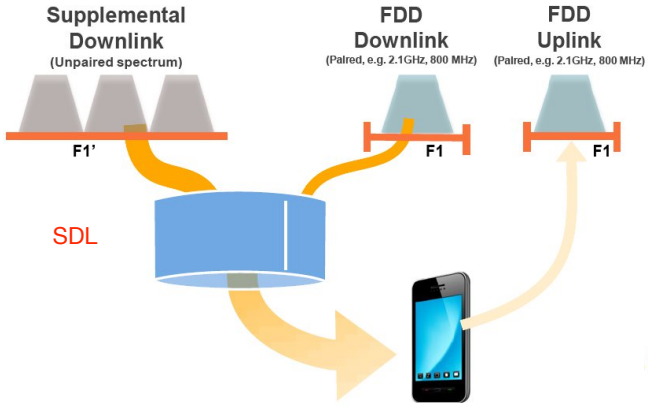
LAA
Includes LBT required for global deployments

3GPP R13
- Supplemental downlink (SDL)
- Dynamic channel selection
- Listen before talk (LBT) complying with global regulations

eLAA and beyond
Enhancements to LAA

3GPP R14 and beyond (1)
- Adds uplink aggregation: Boost uplink data rates and capacity (2)
- Dual Connectivity: Aggregation across non-collocated nodes
- Complexity reduction (3)



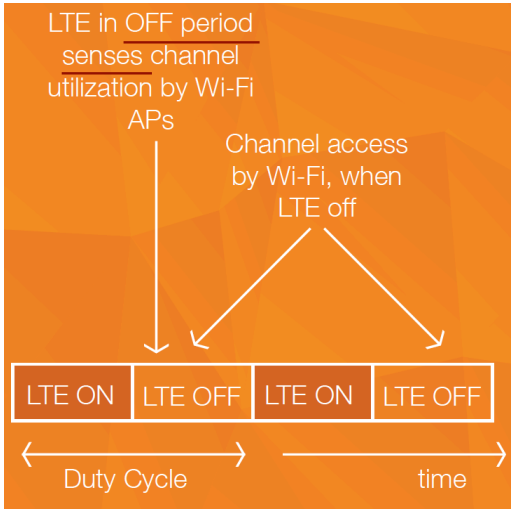


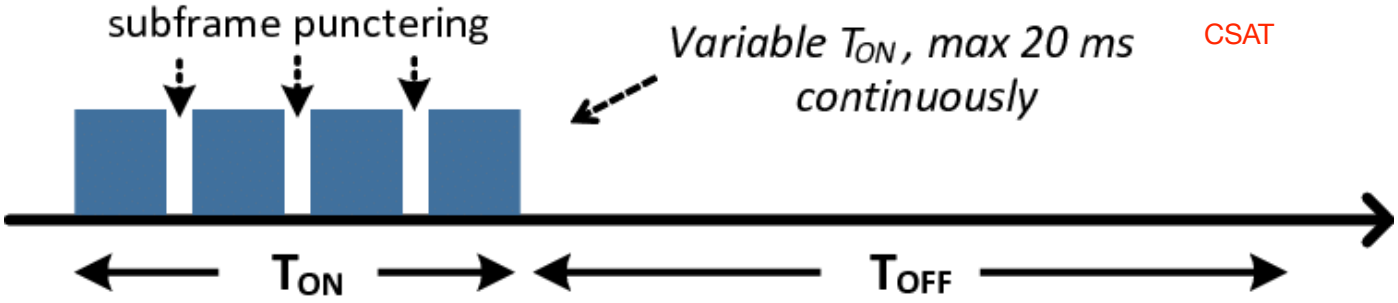
(1) UL aggregation part of Rel. 14 - other features proposed
(2) Aggregation of unlicensed downlink and uplink is possible with either licensed TDD or licensed FDD
(3) Complexity/cost reduction is also applicable to licensed LTE
(4) **SDL**：Supplemental Downlink
(5) **CSAT** (Carrier Sense Adaptive Transmission)：LTE-U adaptive duty cycle

- **Note：CSAT (Carrier Sense Adaptive Transmission)**

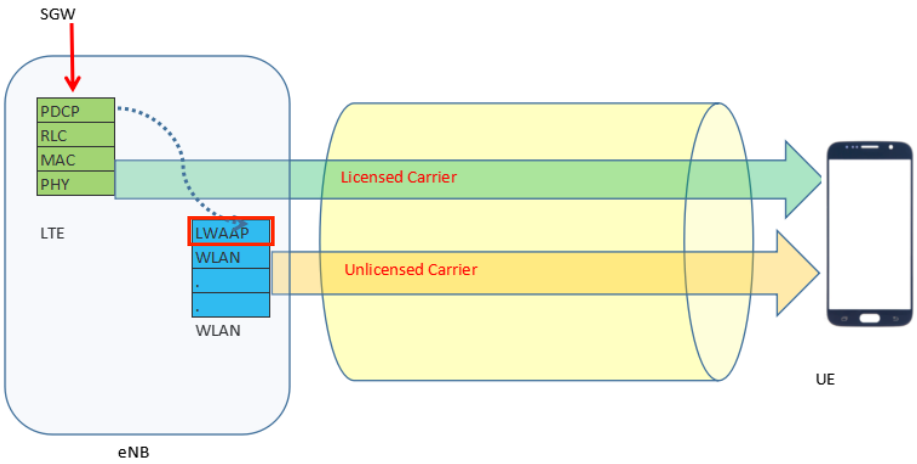
  - In CSAT, the small cell senses the medium for longer duration (around 10 ms to 200 ms), hence creating longer gaps between transmissions, so that other Wi-Fi devices can detect the medium free and transmit achieving relative fairness amongst the spectrum users

  - According to the observed medium activities, the CSAT algorithm increases or decreases LTE duty cycles proportionally and adapts to the channel conditions





- **Note：LWA (LTE WiFi Aggregation) — Collocated & Non-Collocated Scenarios**



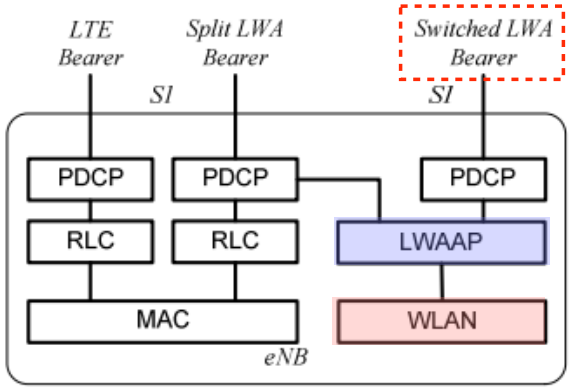


Figure 22A.1.2-1: LWA Radio Protocol Architecture for the Collocated Scenario

Data packets travel from licensed and unlicensed spectrum

PDCP：Packet Data Convergence Protocol
RLC：Radio Link Control
MAC：Medium Access Control
PHY：Physical Layer
LWAAP：LTE-WLAN Aggregation Adaptation Protocol

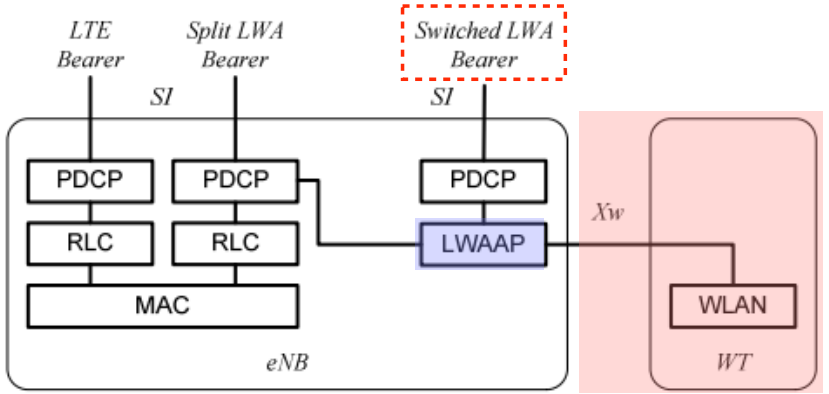
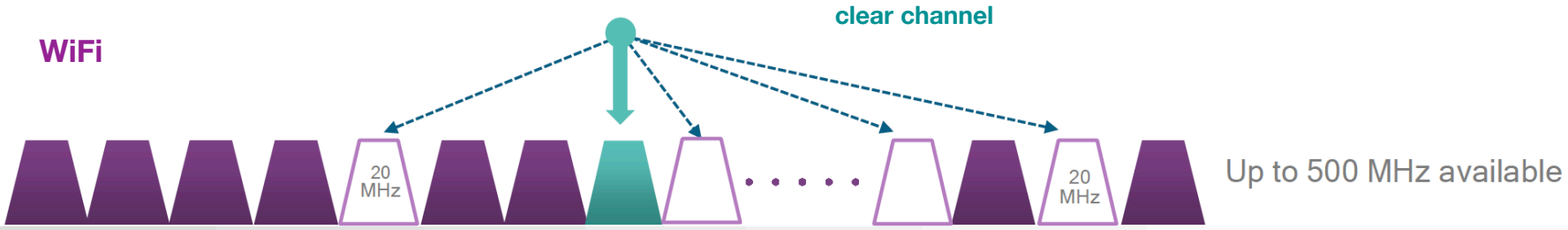


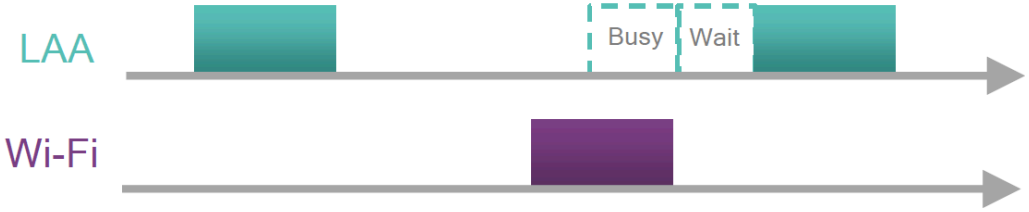
Figure 22A.1.2-2: LWA Radio Protocol Architecture for the Non-Collocated Scenario

LAA Designed to Protect Wi-Fi

Select clear channel: Dynamically avoid Wi-Fi



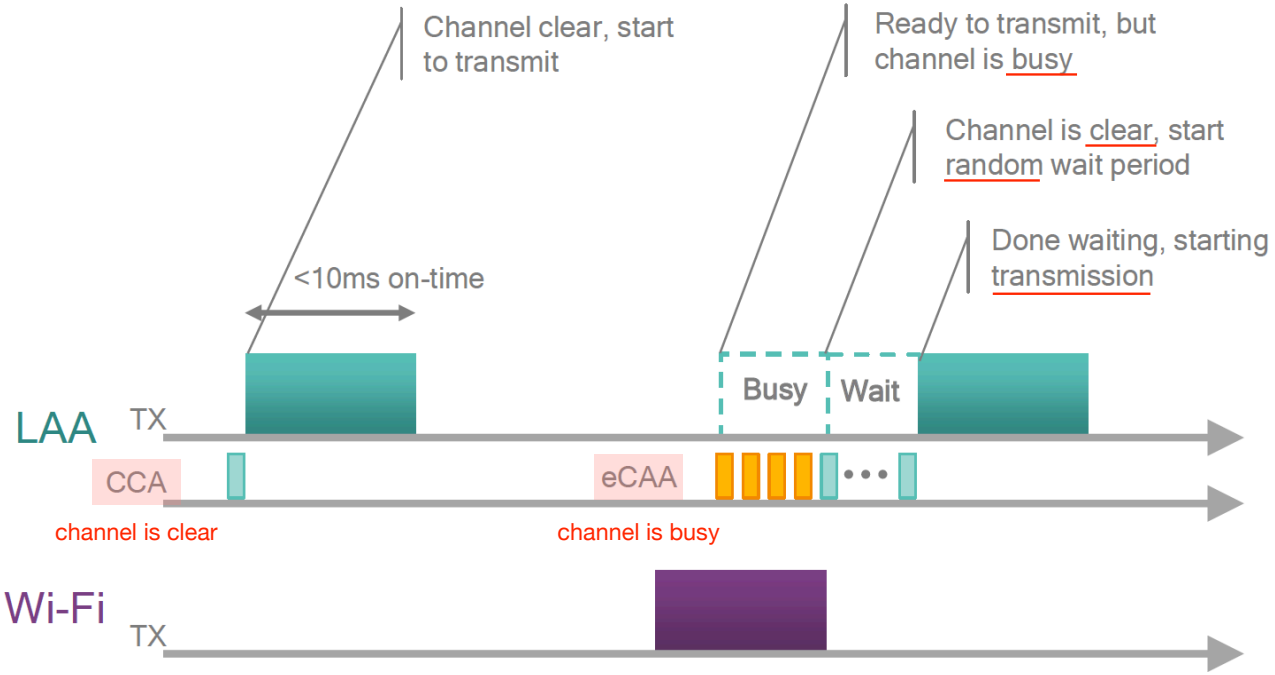
If no clear channel then share fairly: “Listen before talk” (LBT)



Release unlicensed channel at low traffic

LBT Ensures Fair Sharing in Unlicensed 5 GHz

LBT is standardized in ETSI EN 301 893



ED - Energy Detect Threshold

Introducing[1] a more sensitive threshold that is common for all technologies when sensing each other.

CCA - Clear channel assessment

If no signal is sensed based on ED threshold, then go ahead with transmission right away.

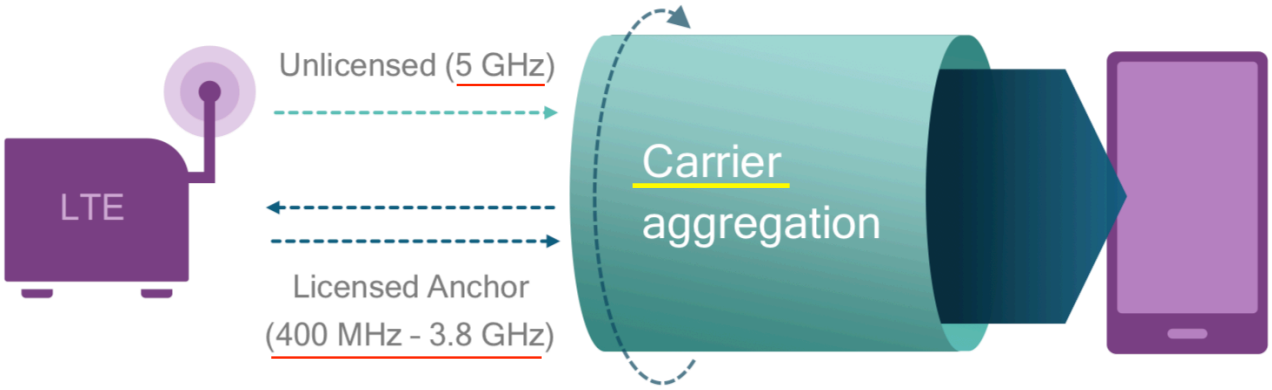
eCCA - Extended CCA

If channel is busy (CCA), then wait for it to become clear. Once it is clear, wait for a random number of additional CCAs indicating that the channel has remained clear before starting transmission.

Designed for fair sharing of 5 GHz	Meets global regulations	Same rule for everyone[1], including Wi-Fi and LTE

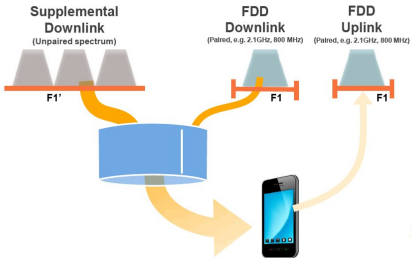
Extending LTE to Unlicensed Spectrum

LTE-U and Licensed Assisted Access (LAA)



- **Path to Gbps speeds**
  By aggregating licensed and unlicensed
- **Seamless and robust user experience**
  With reliable licensed spectrum anchor
- **2x capacity and range**
  Over Wi-Fi capacity in dense deployments[2]
- **Single unified LTE network**
  Common management
- **Fair Wi-Fi coexistence**
  Fundamental design principle

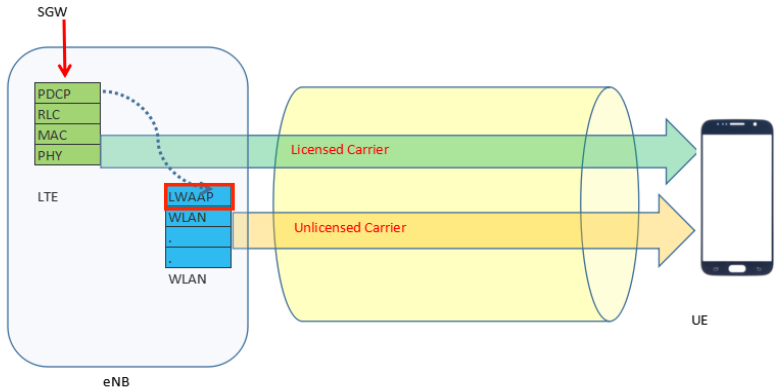
Supplemental Downlink (SDL) to boost downlink[1]



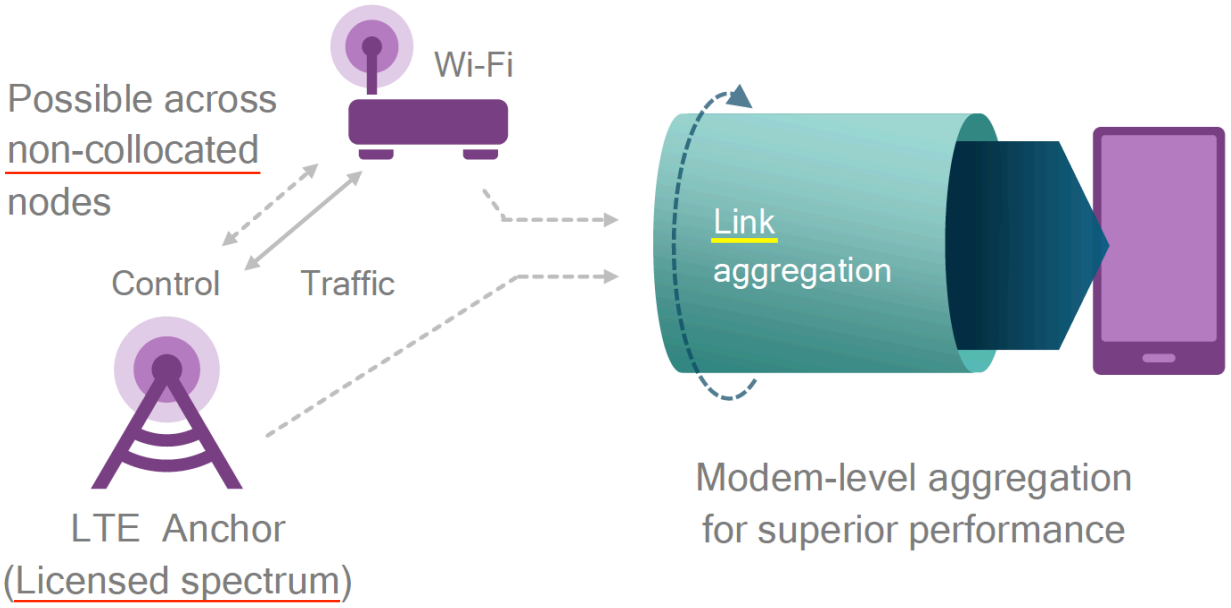
Aggregating with either licensed TDD or licensed FDD is possible with SDL

LWA for Existing and New Carrier Wi-Fi

LTE - Wi-Fi link aggregation part of 3GPP Release 13



Leverages new/existing carrier Wi-Fi
(2.4 & 5 GHz unlicensed spectrum)

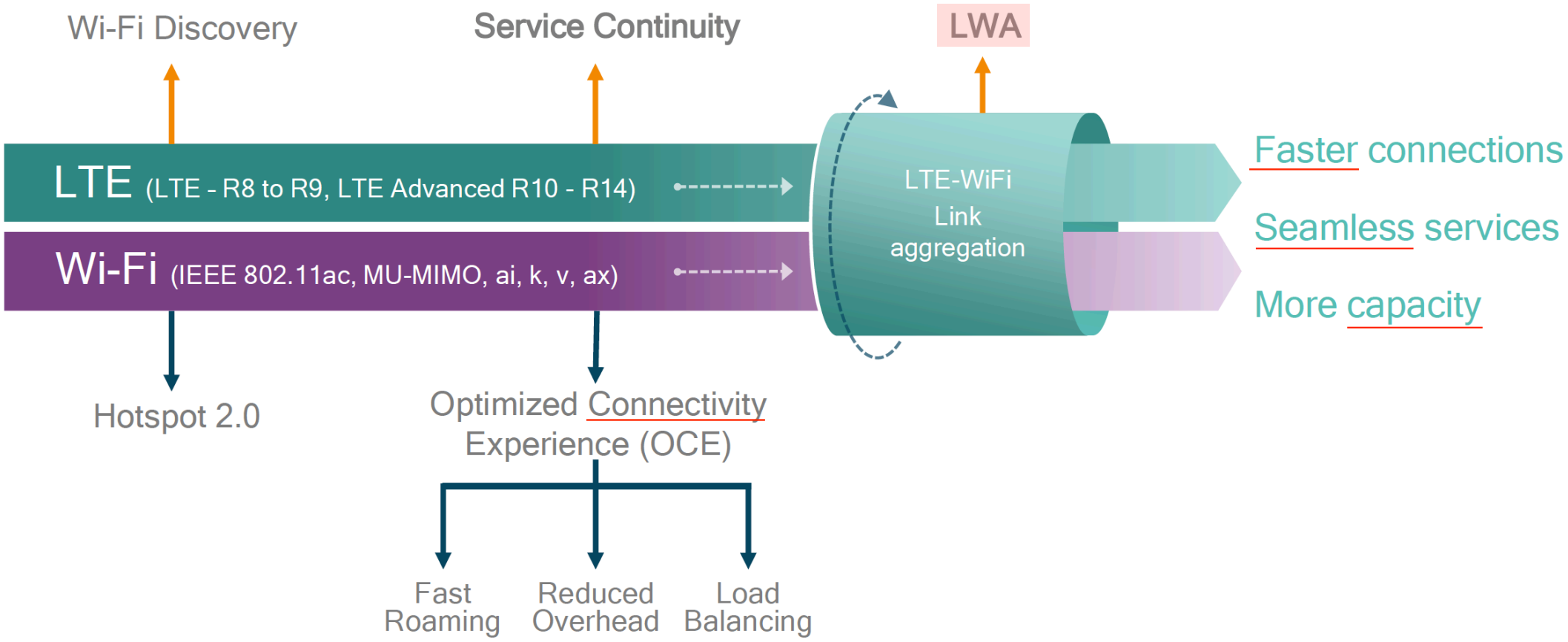


Modem-level aggregation
for superior performance

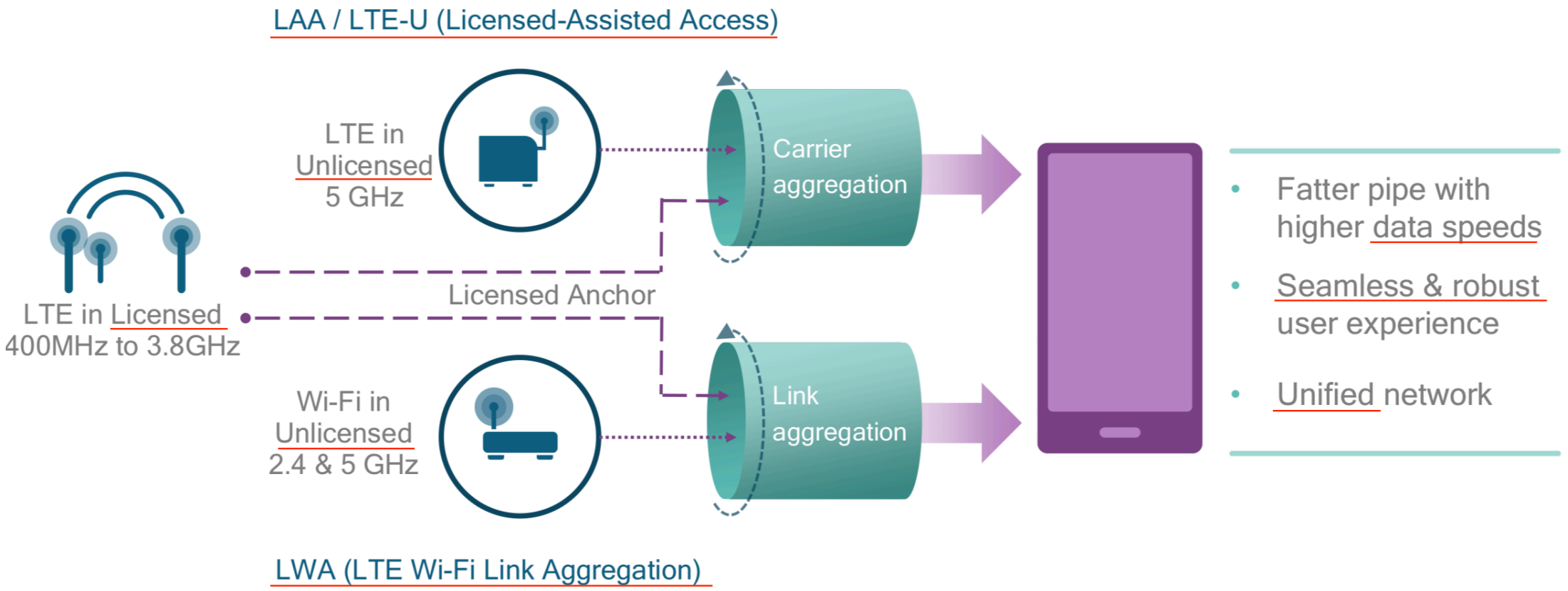
- **Seamless & robust user experience**
  Licensed anchor for control and mobility
- **Unified network**
  Operator LTE network in full control of Wi-Fi
- **Better performance**
  Simultaneously using both LTE and Wi-Fi links

Aggregation Part of Larger LTE - Carrier Wi-Fi Convergence

Also going beyond standards features–driving convergence down to the modem level



Aggregation with licensed anchor for best performance



Shared Spectrum Technologies in LTE

LSA[1]

Technically extensive pilot in France with Ericsson and Red in Jan 2016

LTE-U

Designed the original technology, commercialized by the LTE-U Forum, deployed in the US

LAA[2]

First over-the-air trials with DT 2015, multiple commercial deployments globally and 2nd gen. Gigabit LTE tested 2017

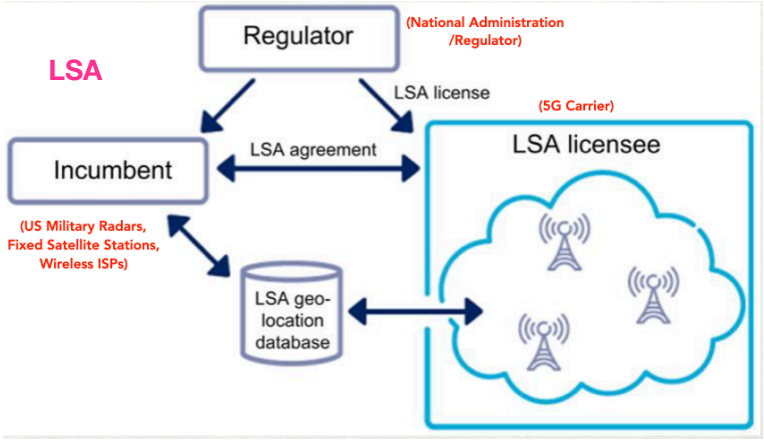
MULTEFIRE™

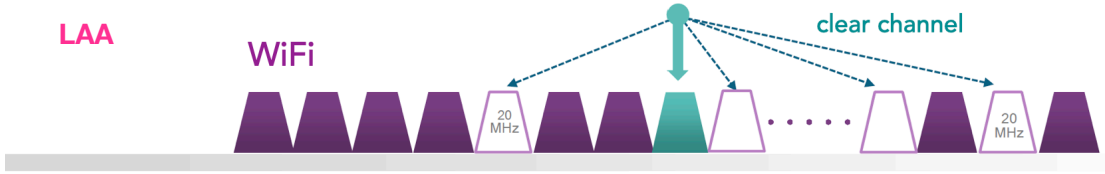
A founder of the MulteFire Alliance, first OTA connection Oct. 2016, Release 1.0 specification Jan. 2017

ALLIANCE cbrs

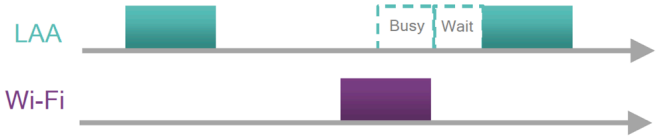
A founder of the CBRS[3] Alliance and a key contributor to coexistence

LSA：Licensed Shared Access　LAA：Licensed Assisted Access　CBRS：Citizen's Broadband Radio System





If no clear channel then share fairly: "Listen before talk" (LBT)



MulteFire – LTE-like Performance with Wi-Fi-like Simplicity

Operating 4G LTE technology solely in unlicensed spectrum, e.g., 5 GHz

LTE-like performance

- Enhanced capacity and range
- Improved mobility, quality-of-experience
- Hyper-dense, self-organizing deployments

Harmoniously coexist with Wi-Fi, LTE-U/LAA

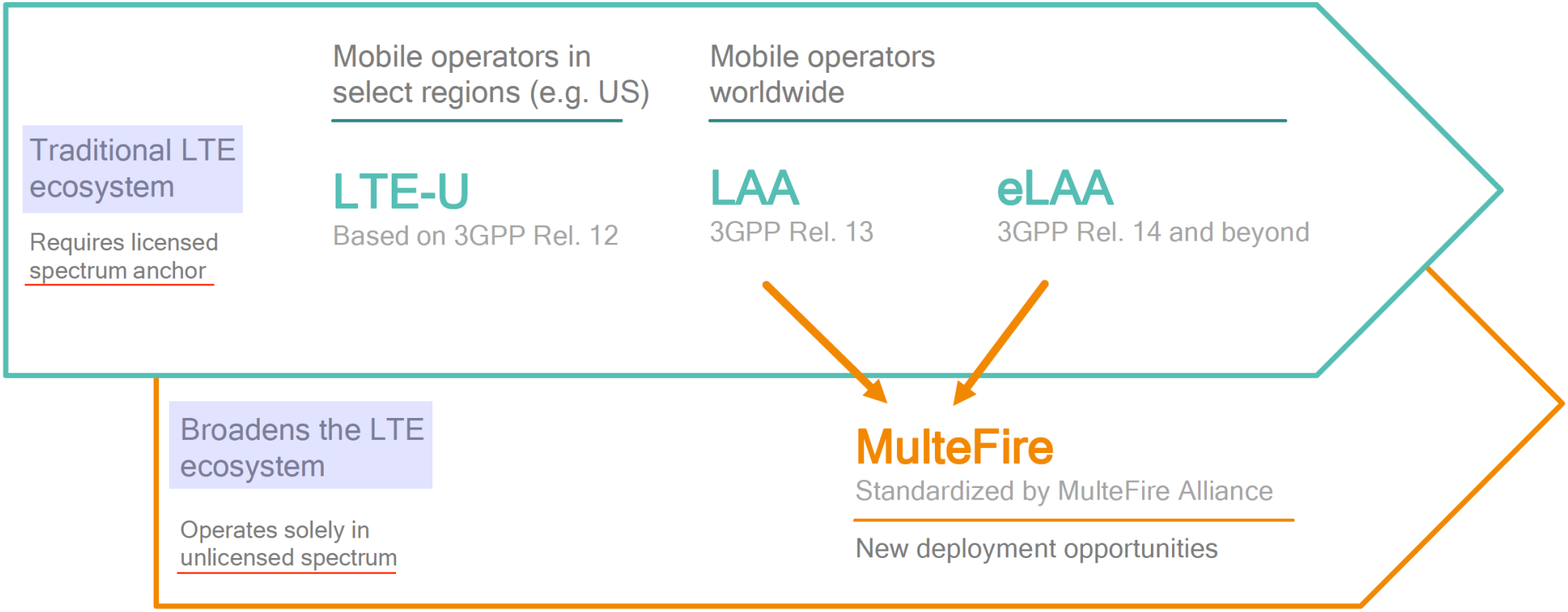
Wi-Fi-like simplicity

- Operates in unlicensed spectrum
- Leaner, self-contained network architecture
- Suitable for neutral host deployments

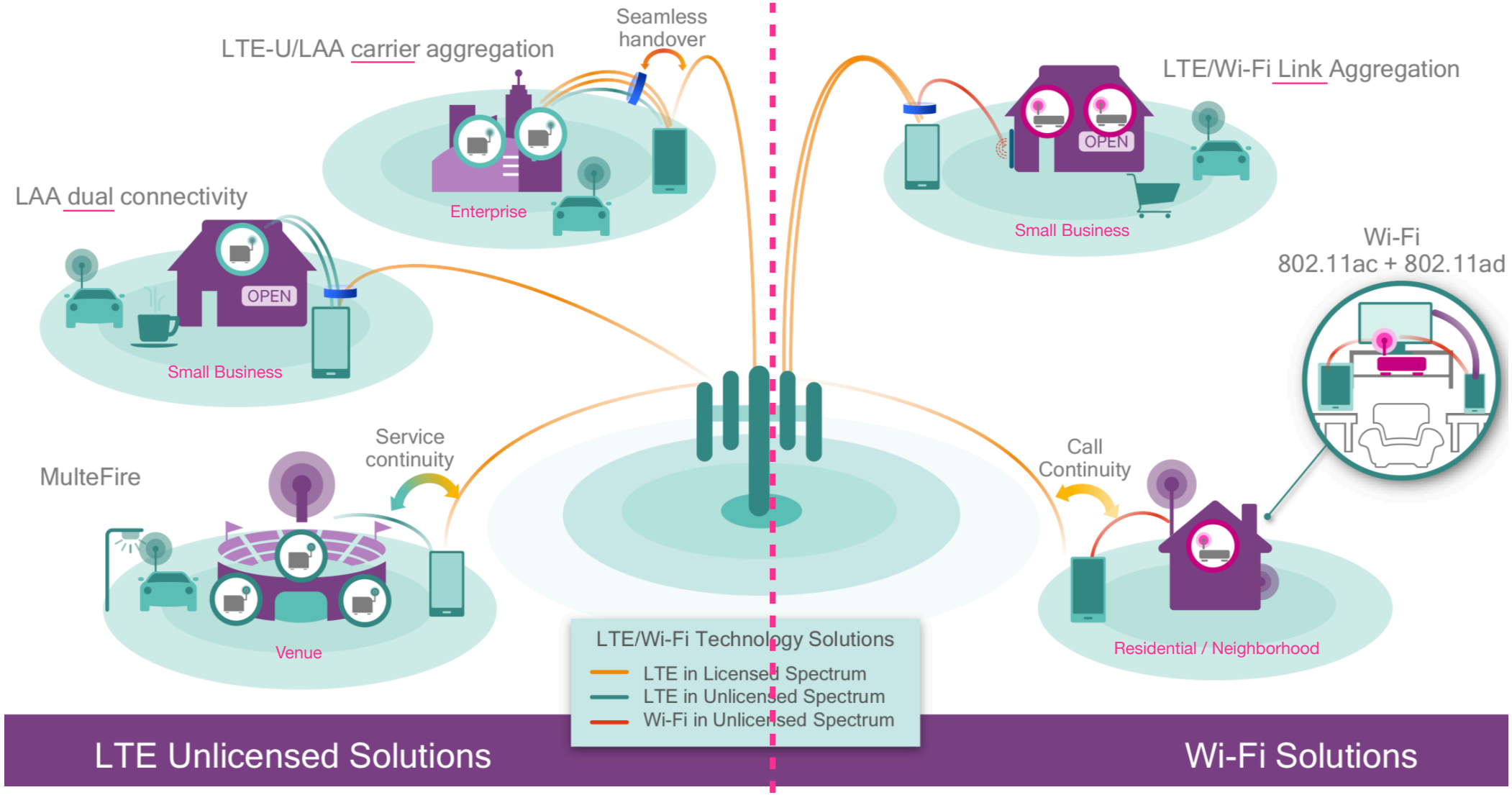
Broadens LTE ecosystem to new deployment opportunities

MulteFire is based on 3GPP Standards

Similar performance and same coexistence as LAA in unlicensed



Multiple Technologies for Multiple Deployment Scenarios

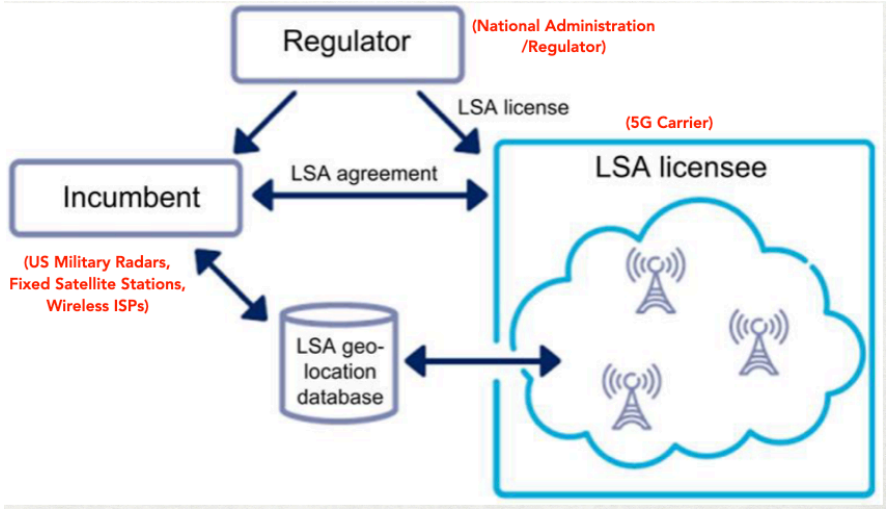


Licensed Shared Access (LSA)

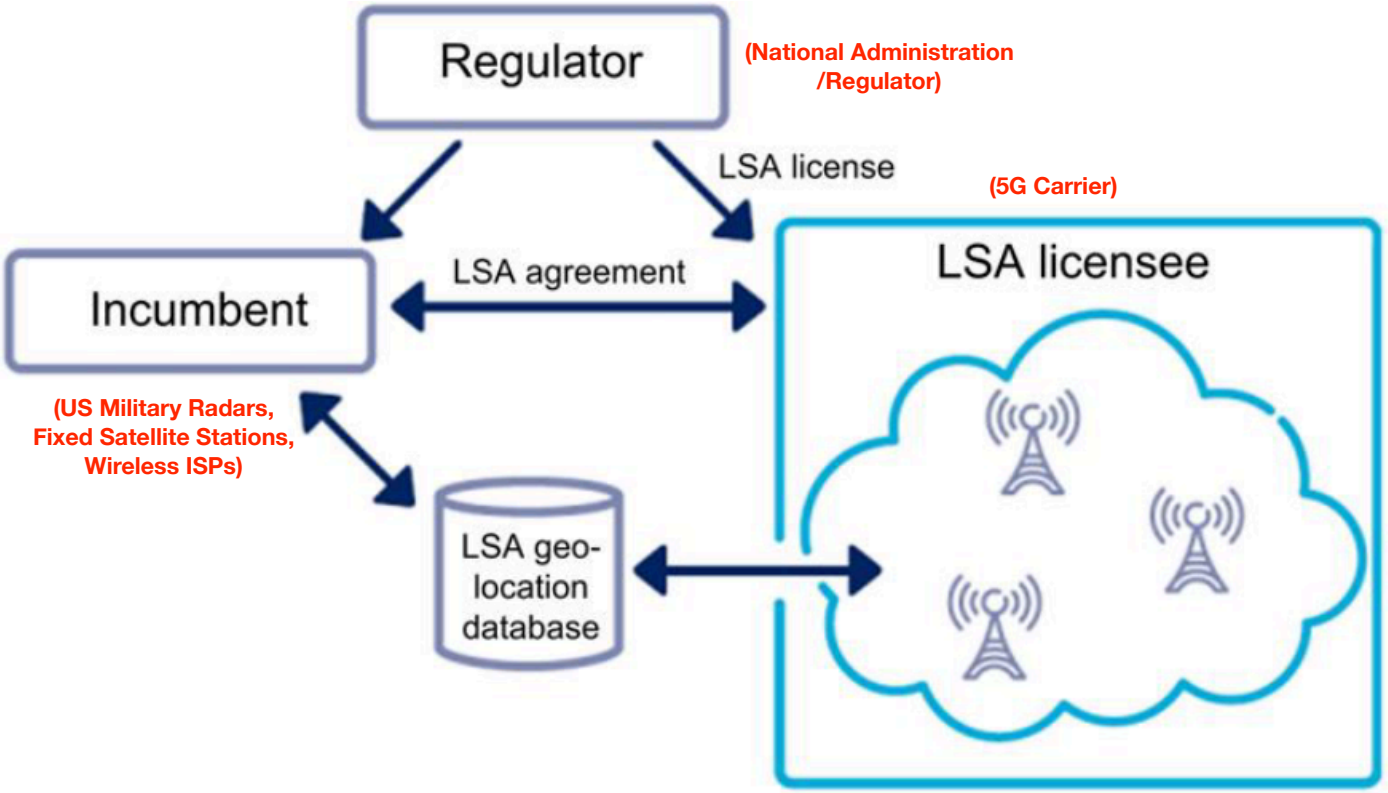
- A regulatory approach to facilitate access for additional licensees (e.g. 5G carrier) in bands which are already in use by one or more incumbent users (holders of right to use, e.g. US Military Radars, Fixed Satellite Stations, Wireless ISPs, etc.)

- A concept to dynamically share this band, whenever and wherever it is unused by the incumbent users

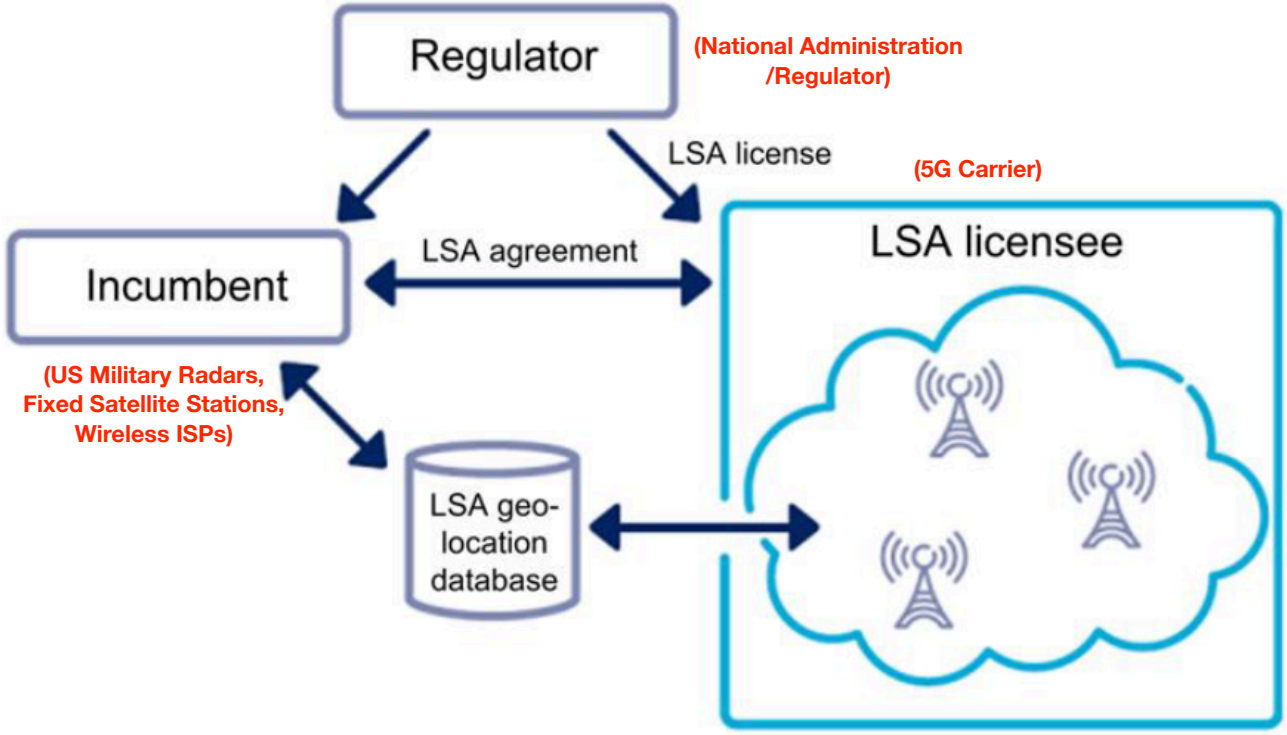
- Shared use of the spectrum is only allowed on the basis of an individual authorization (i.e. licensed)



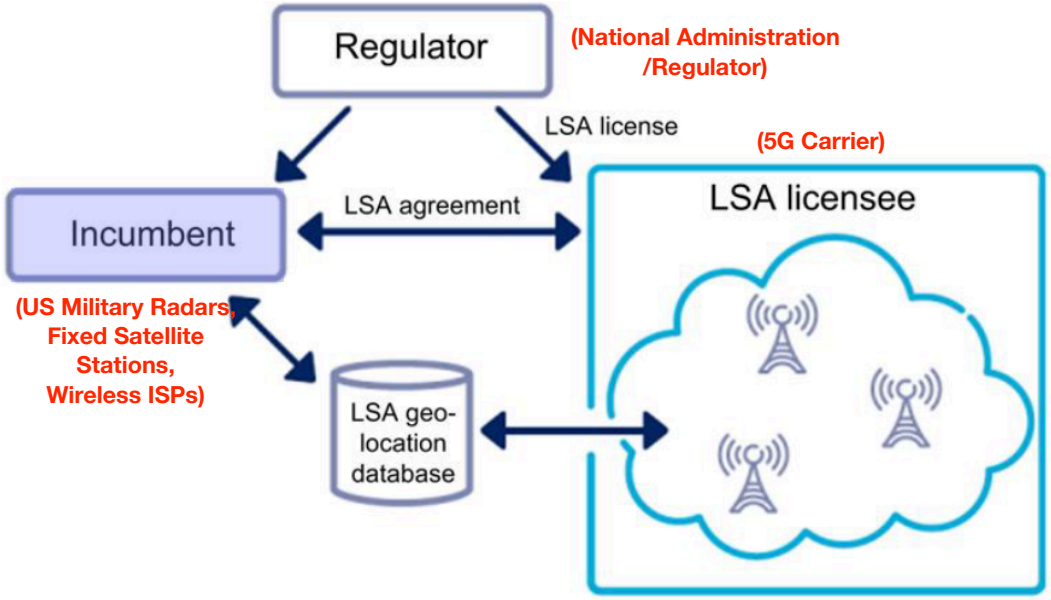
- Regulatory framework could provide
  - The LSA spectrum to be licensed to be identified by the government
  - A private commercial agreement between incumbent and LSA licensee



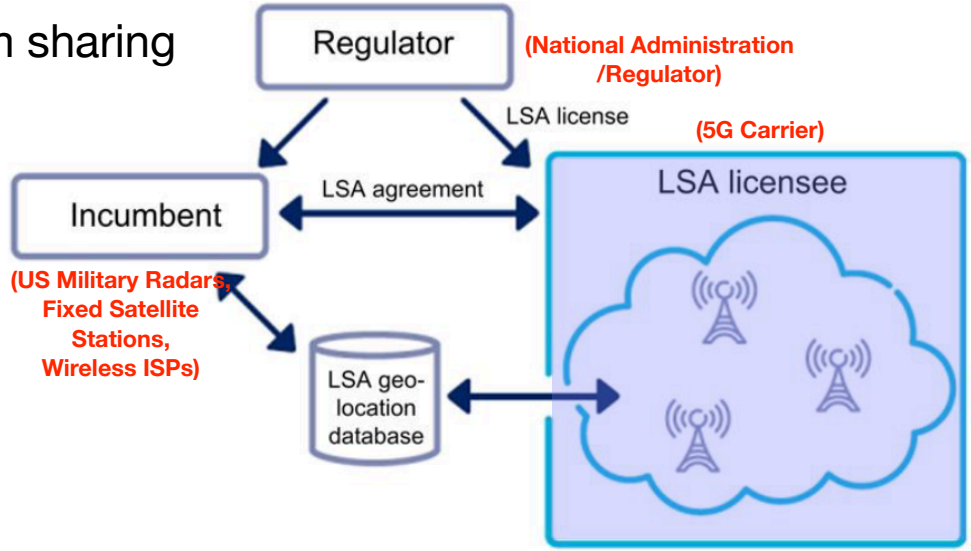
- Within the scope of the LSA concept
  - All spectrum users (incumbent) are authorized to use the spectrum in accordance with sharing rules included in their rights of use of spectrum on the primary basis (primary licensee)
  - All the authorized sharing users (LSA licensee), including incumbents with LSA mode, are allowed to provide a certain Quality of Service (QoS) to their subscribers



- The main parties concerned in the management of LSA licensed spectrum sharing
  - ***Incumbent (Incumbent spectrum user)***
    - A current holder of the rights to spectrum use
    - May offer an unused spectrum for one or more LSA sharing licenses
    - May negotiate spectrum-sharing features with LSA licensees based on the rules specified by the Regulator for licensed spectrum sharing



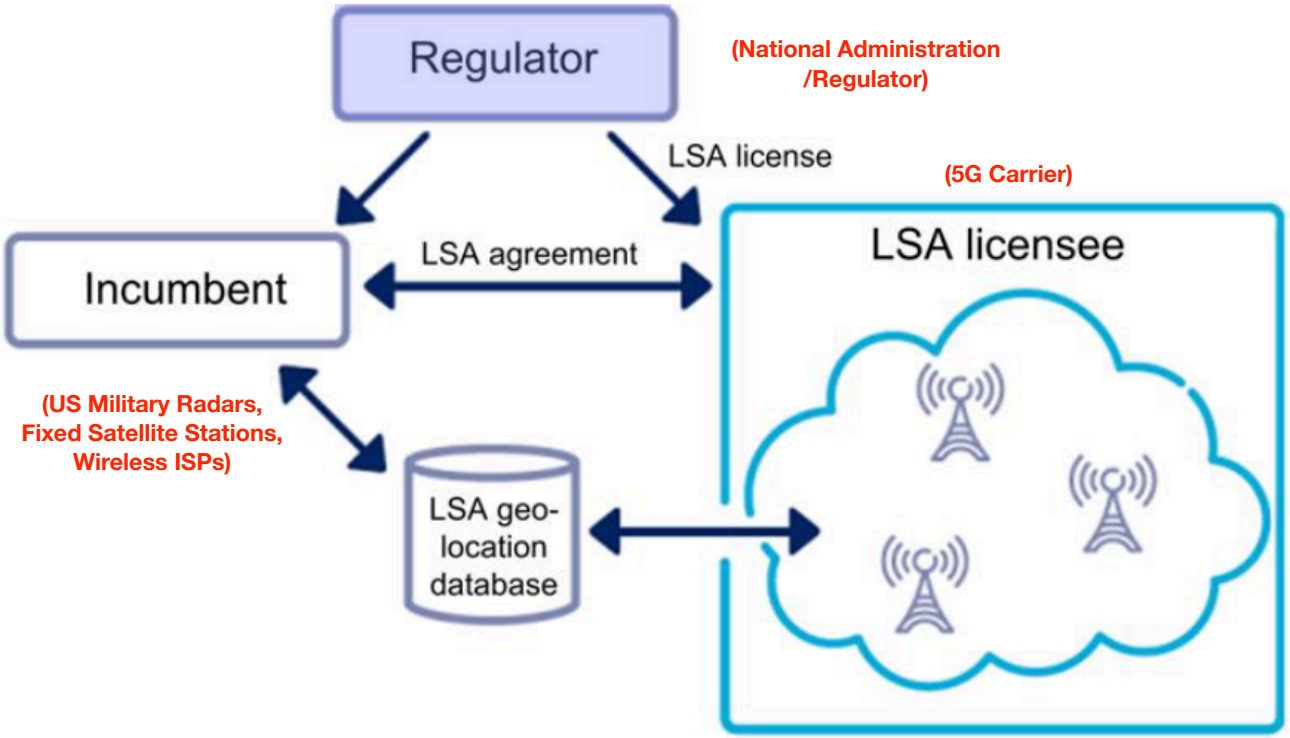
- ***LSA Licensee***
  - An entity operating as a 5G carrier, which holds individual rights of use to LSA spectrum resources
  - Use spectrum additional to the one allocated on a shared basis with a primary incumbent spectrum holder
  - The license is issued by the National Administration / Regulator
  - The licensee also obtains a spectrum sharing agreement, i.e., a treaty between the principal holder of rights to use the spectrum and LSA licensees
  - The agreement specifies conditions of LSA spectrum sharing



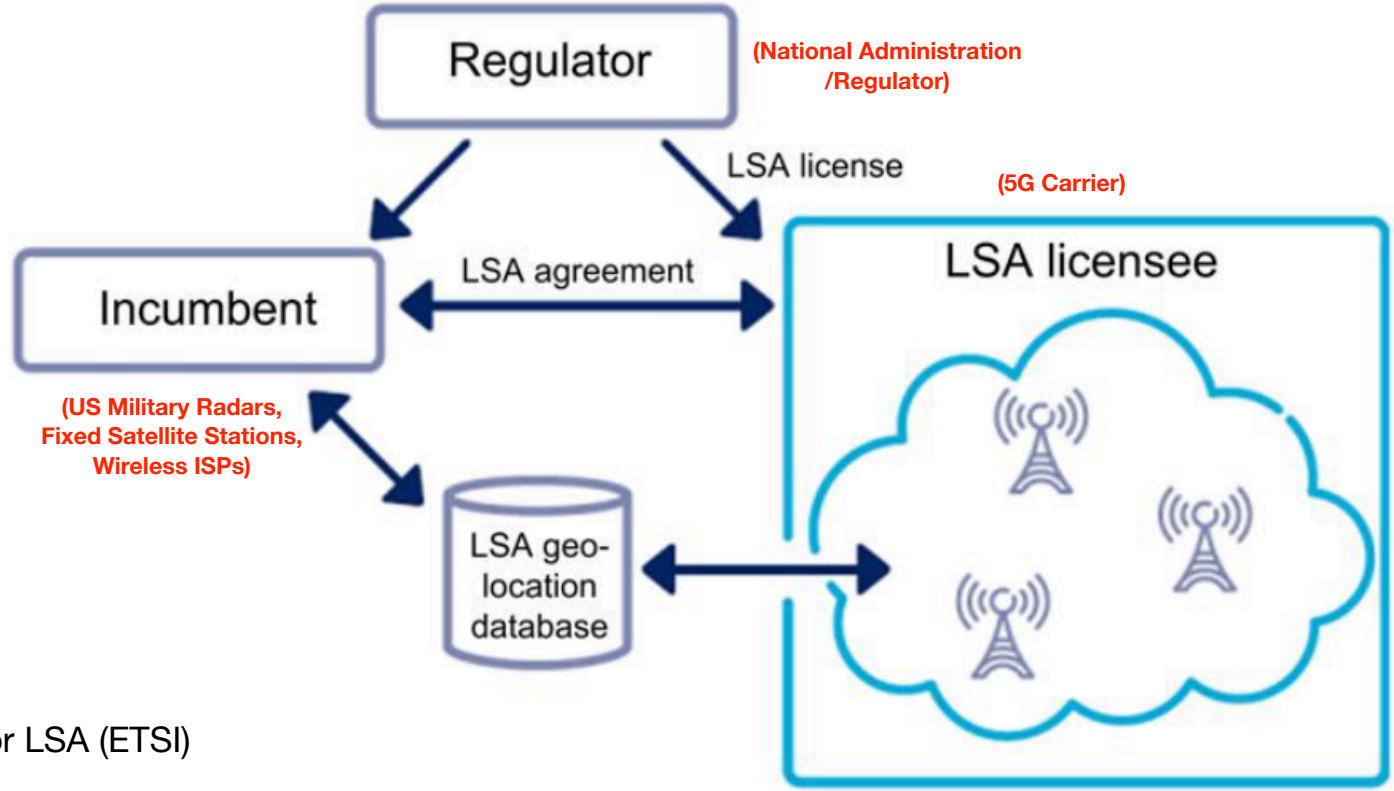
- ***Regulator***

  - A body which guarantees the rights of LSA licensees and issues spectrum sharing licenses to them

  - Set the rules for granting a license for spectrum sharing with reference to the incumbent spectrum holder

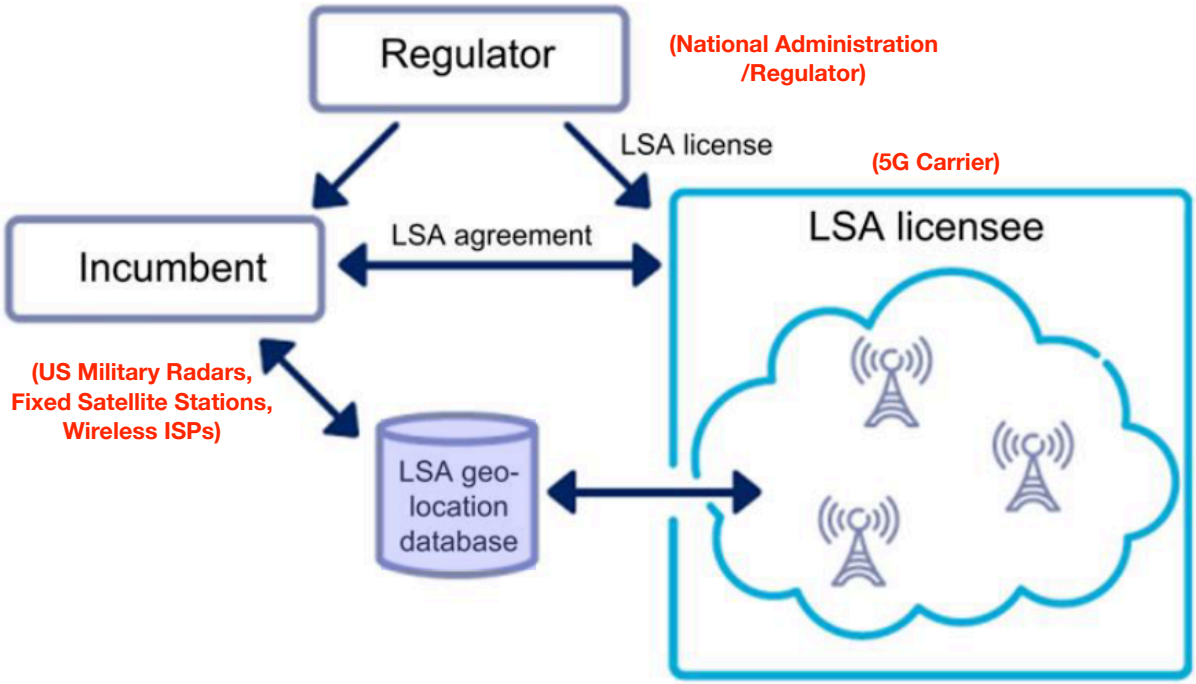


- Cooperation between the main players and a regulatory framework for licensed spectrum sharing
  - A similar shared spectrum approach could be used for 2.3-2.4 GHz band in Europe and 3.5 GHz band in the US

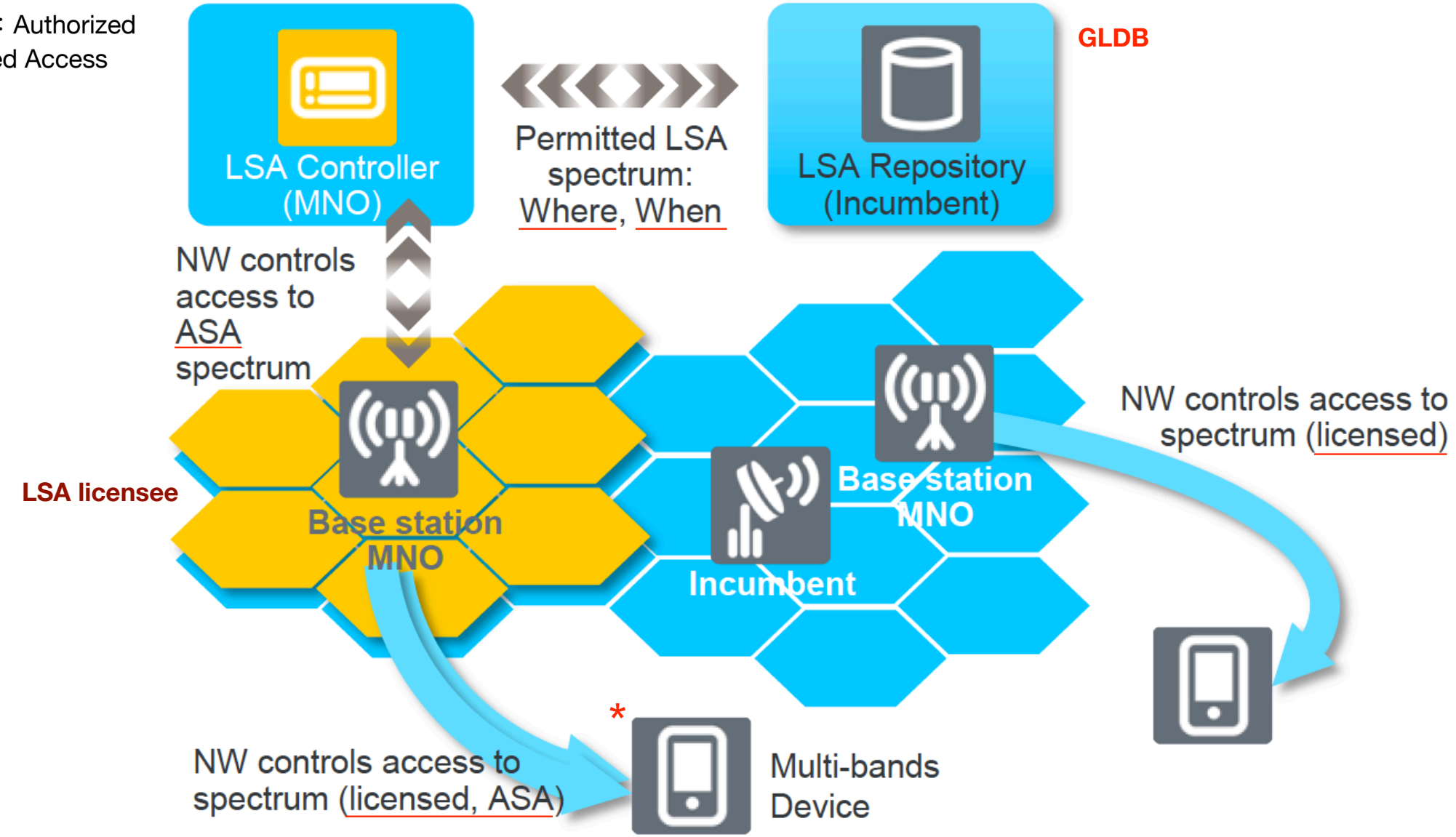


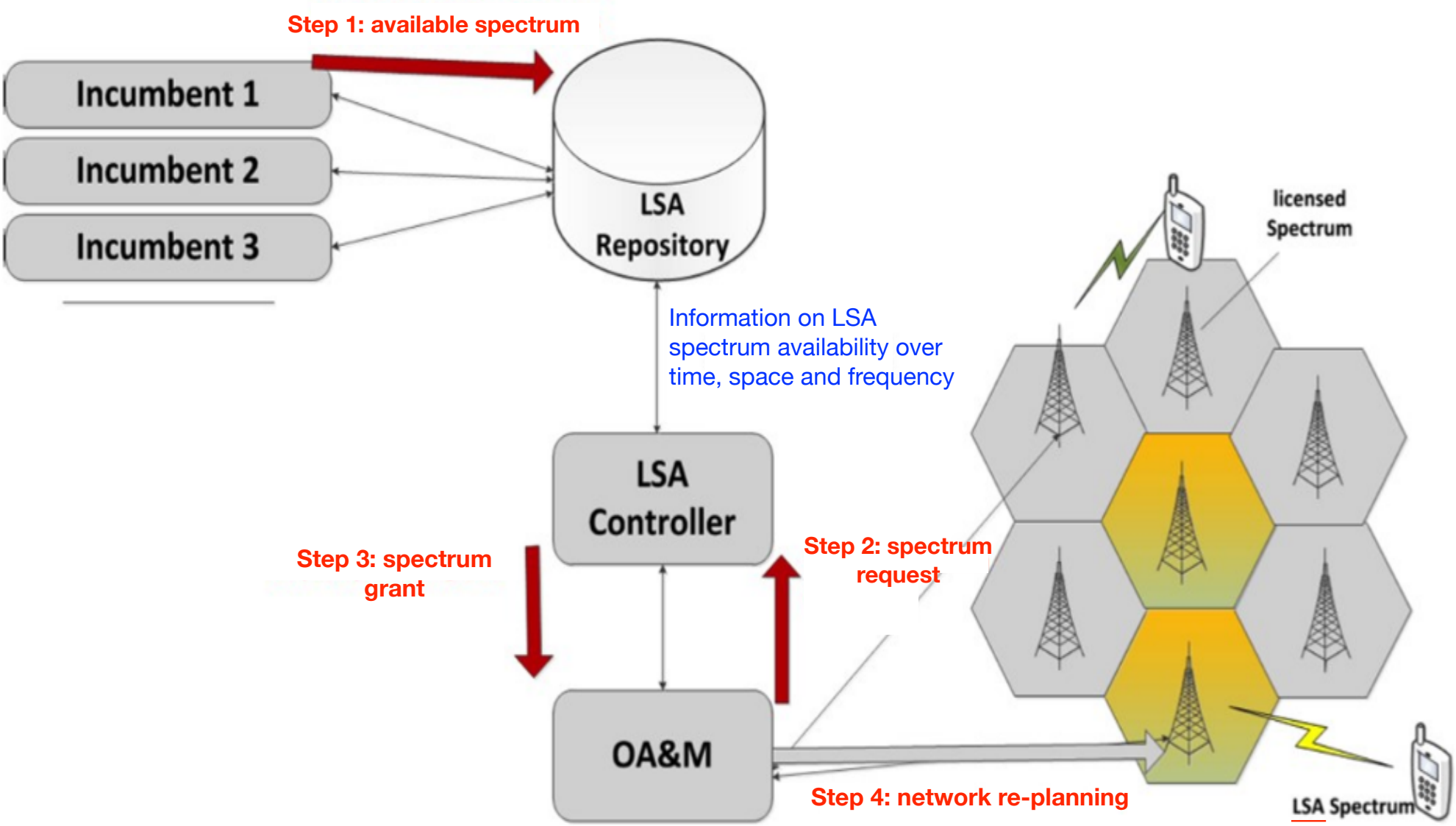
Co-operation and the main players for LSA (ETSI)

- Main advantage of LSA concept
  - The number of LSA licensees is limited and that they have on-line access to current information (whenever and wherever) associated with the spectrum usage situation for each user
  - Such information may be retrieved from Regulator's GeoLocation Data Base (GLDB)



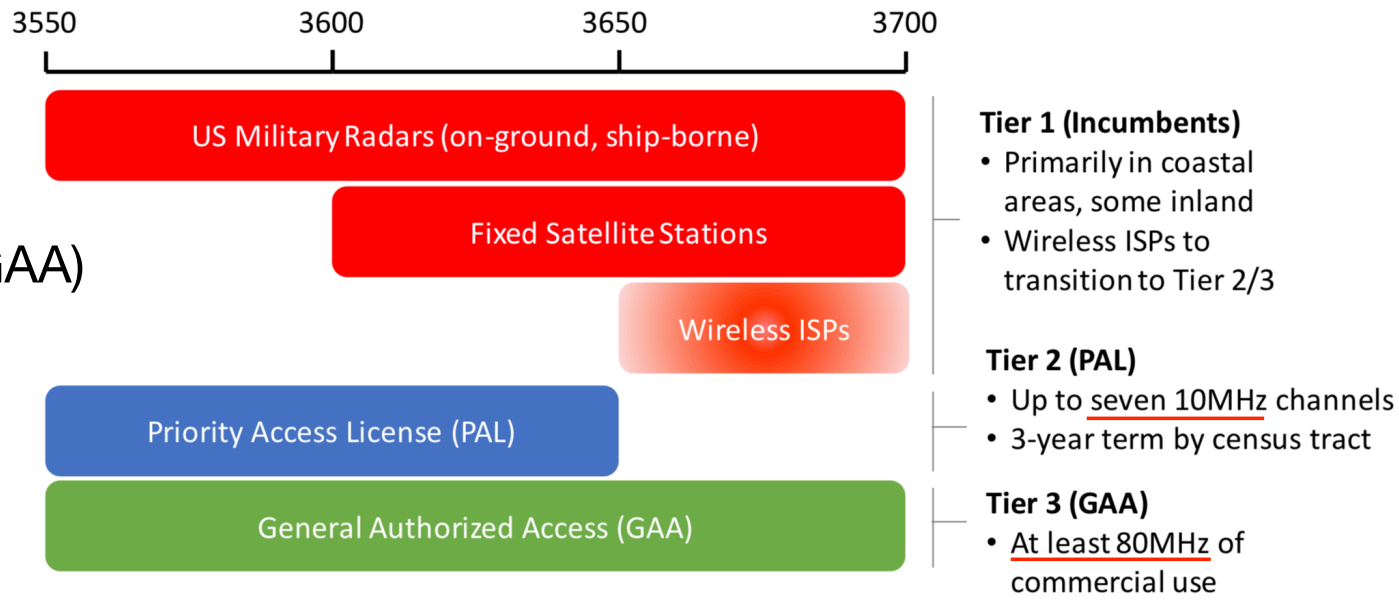
ASA：Authorized Shared Access




Step 1: available spectrum
Incumbent 1
Incumbent 2
Incumbent 3
LSA Repository
Information on LSA spectrum availability over time, space and frequency
LSA Controller
Step 3: spectrum grant
Step 2: spectrum request
OA&M
Step 4: network re-planning
licensed Spectrum
LSA Spectrum

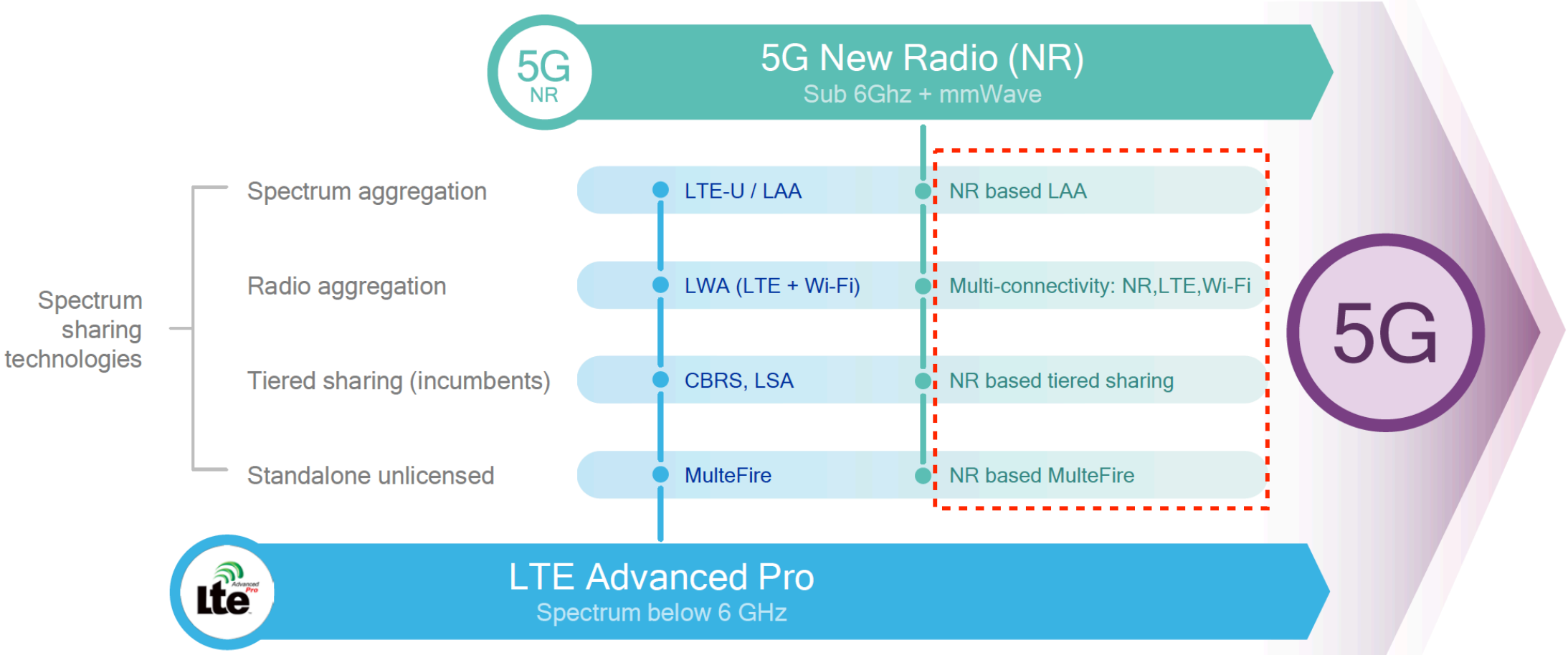
Citizens Broadband Radio Service (CBRS)

- A 150 MHz wide broadcast band of 3.5 GHz band (3550 MHz to 3700 MHz)
- Wireless carriers using CBRS might be able to deploy 5G mobile networks without having to acquire spectrum licenses
- CBRS 3-tier Shared Spectrum Licensing structure
  - Incumbent
  - Priority Access License (PAL)
  - General Authorized Access (GAA)

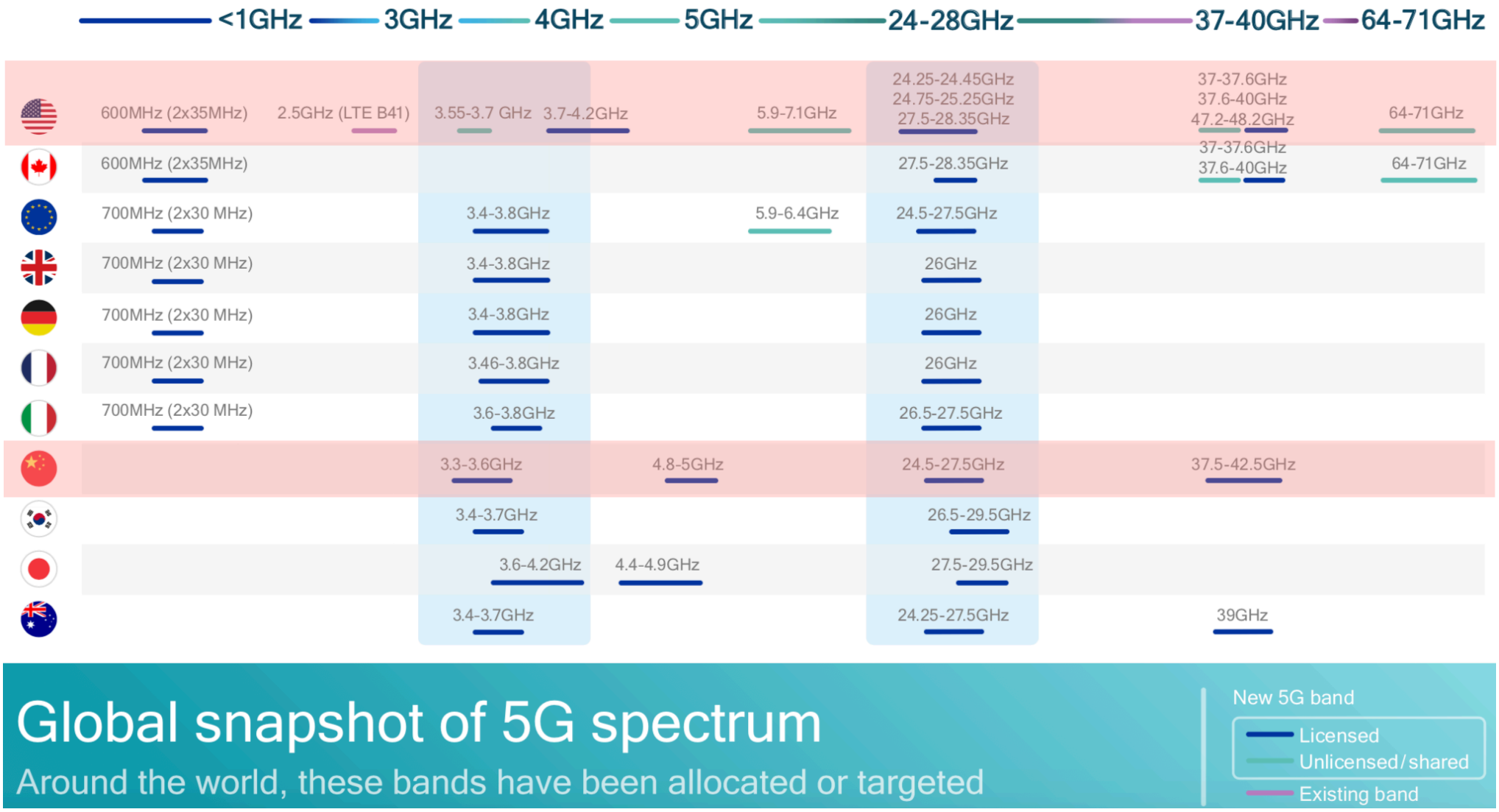


5G Spectrum Sharing Today

Building on LTE-U/LAA, LWA, CBRS, LSA and MulteFire[1]



Global 5G Spectrum



Global snapshot of 5G spectrum

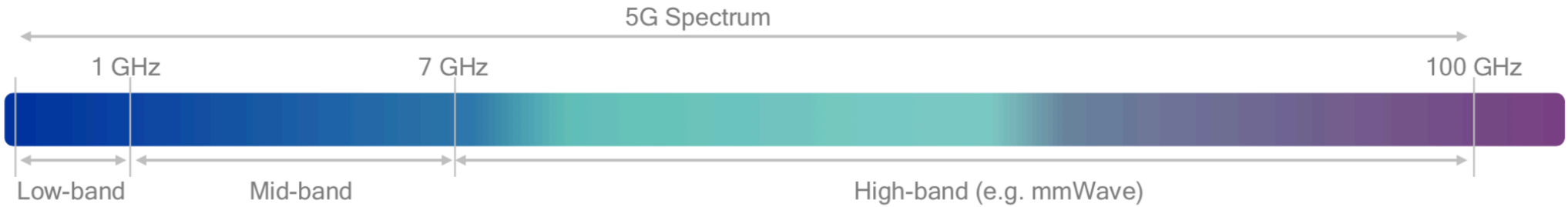
Around the world, these bands have been allocated or targeted

New 5G band

- Licensed
- Unlicensed/shared
- Existing band

FCC is Driving Key Spectrum Initiatives to Enable 5G

Across low-band, mid-band, and high-band including mmWave



Low-band
Broadcast incentive auction

- Successfully auctioned a portion of the 600 MHz band that generated $19.8B in proceeds after assignment phase
- Includes 70 MHz (2 x 35 MHz) of licensed spectrum and 14 MHz for unlicensed use
- Spectrum availability timing aligns with 5G

Mid-band
Citizens Broadband Radio Service (CBRS)

- Opening up 150 MHz in 3.5 GHz band with 3-tier sharing with incumbents, PAL[1], GAA[2]
- FCC to improve PAL rules in 2017 to make them suitable for 5G
- CBRS Alliance formally launched to drive an LTE-based ecosystem
- FCC Notice of Inquiry on 3.7-4.2 GHz and 5.9-7.1 GHz

High-band
2016 Spectrum Frontiers Ruling[3] and second mmWave ruling in 2017

- In 2016, FCC announced opening up of 11 GHz in multiple mmWave bands, 70% of newly opened spectrum is shared or unlicensed
- Unanimously approved. FCC also asked for comment on other candidate bands identified for IMT-2020
- In Nov. 2017, FCC adopted second order allocating 24.25-24.45, 24.75-25.25 GHz, and 47.2-48.2 GHz

CBRS：Citizens Broadband Radio Service

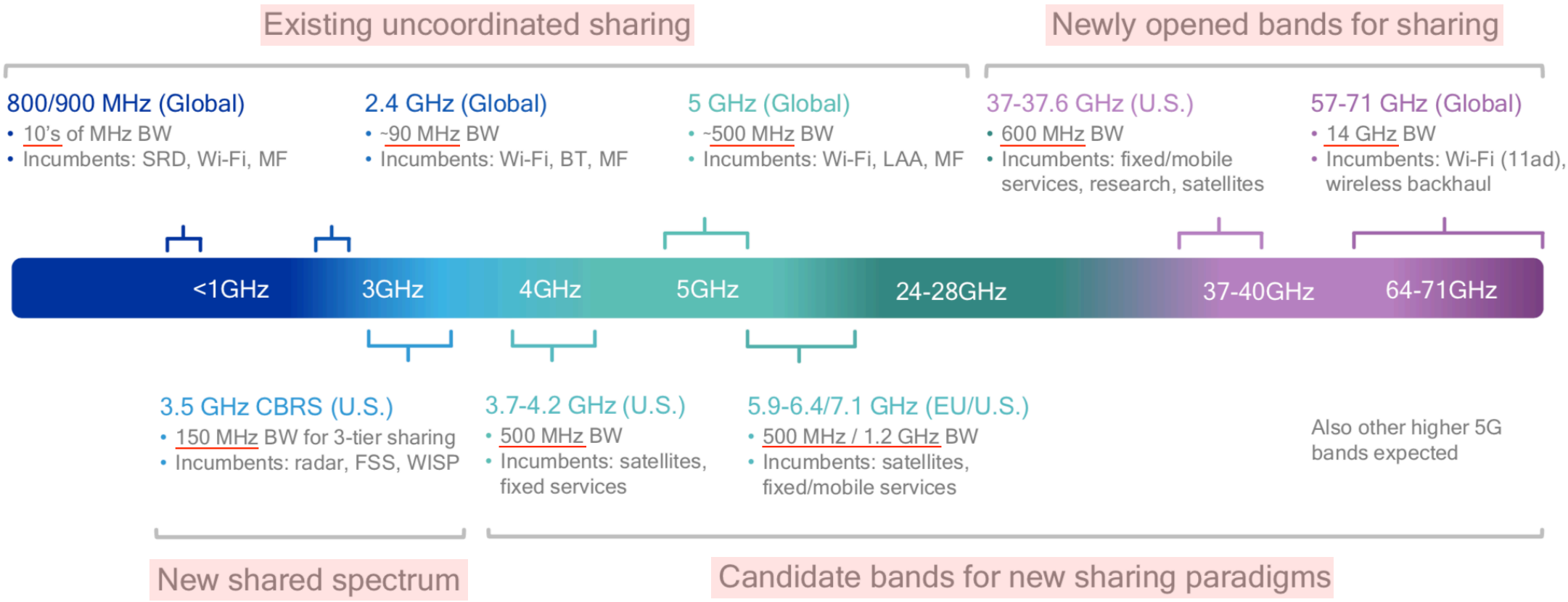
— A 150 MHz wide broadcast band of the 3.5 GHz band (3550 MHz to 3700 MHz)

— Wireless carriers using CBRS might be able to deploy 5G mobile networks without having to acquire spectrum licenses

PAL：Priority Access Licensee　　GAA：General Authorized Access

Opportunity to Improve Spectrum Utilization by Sharing

Key candidate global spectrum bands for 5G spectrum sharing

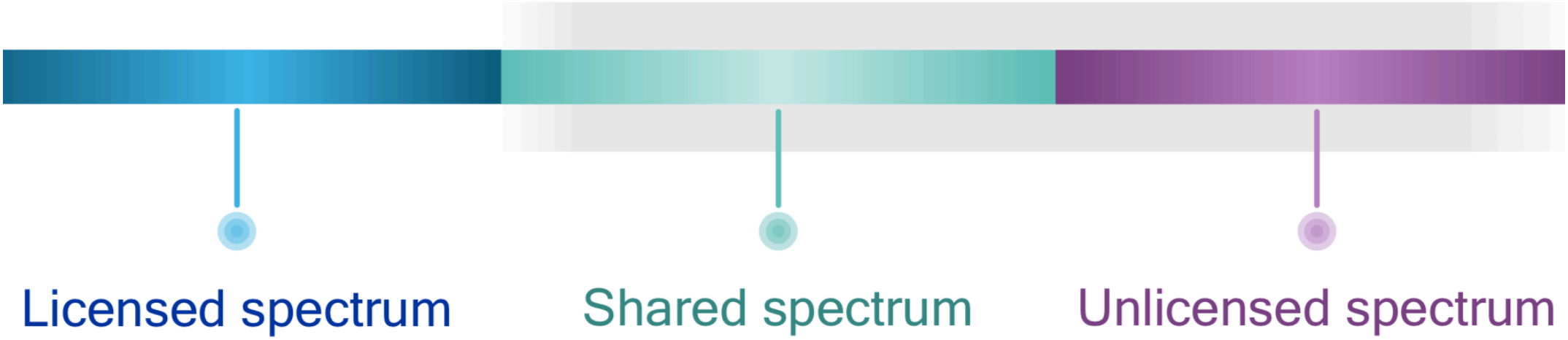


SRD：Short Range Device　　MF：Multefire　　FSS：Fixed-Satellite Service　　WISP：Wireless Internet Service Provider

Spectrum Sharing Provides Critical Benefits for 5G

Spectrum sharing

- Unlocks more spectrum
- New deployment scenarios
- Increases spectrum utilization



Spectrum Sharing Valuable for Wide Range of Deployments

Licensed spectrum aggregation

Better user experience with higher speeds

Enhanced local broadband

Neutral host, neighborhood network

Private 5G networks

Industrial IoT, Enterprise

Enhancing existing deployments,

Examples today: Gigabit LTE with LAA[1]

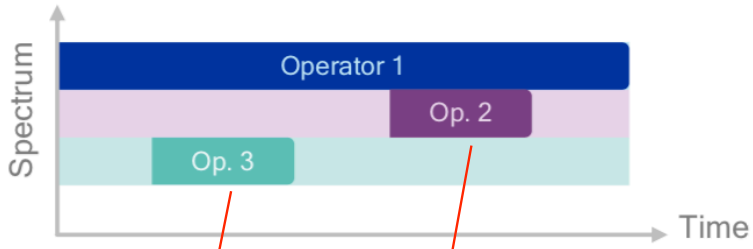
New types of deployments,

Examples today: Private LTE networks

Better Spectrum Utilization with Guaranteed Bandwidth

Asymmetric traffic

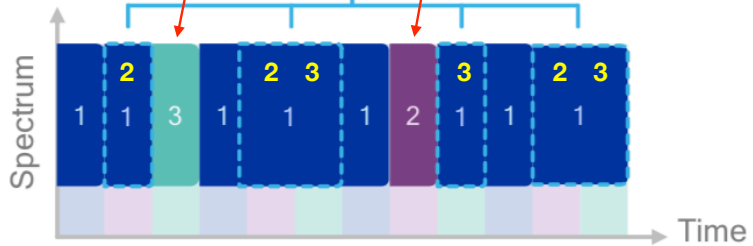
Licensed spectrum (FDM)



Unused slots available

Operator 1 has additional offered traffic and opportunistically use these slots

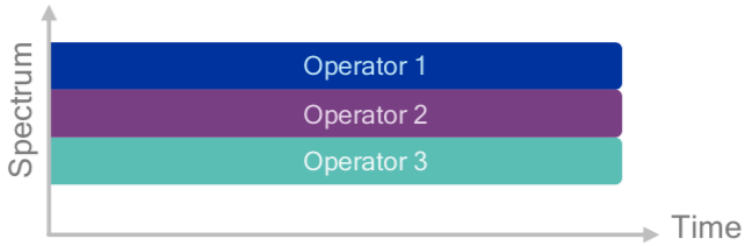
NR-SS with guaranteed resources

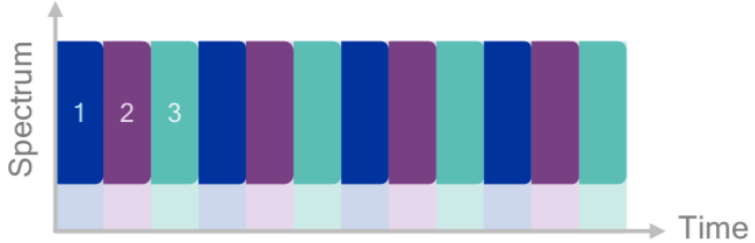


Guaranteed resources rotate over operators

Higher user data speeds from opportunistic sharing of a wider bandwidth (aka trunking gains)

Full traffic





Guaranteed resources rotate over operators

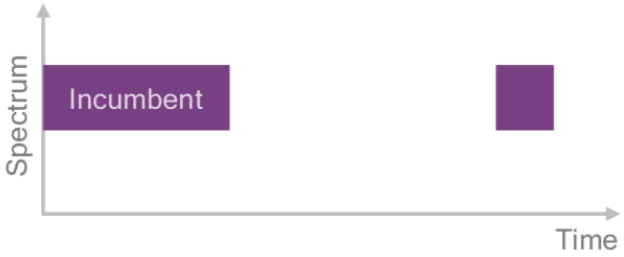
Guaranteed bandwidth similar to licensed spectrum

NR-SS：NR Spectrum Sharing

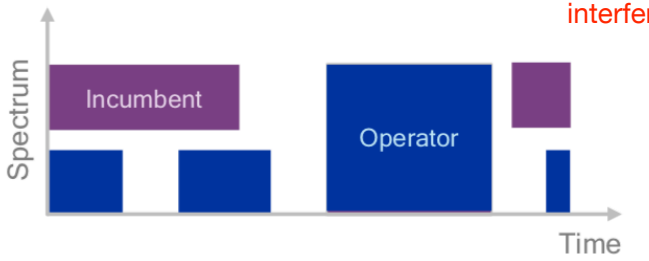
Spectrum can be Shared both Horizontally and Vertically

Better spectrum utilization from dynamic spectrum sharing

Static allocation

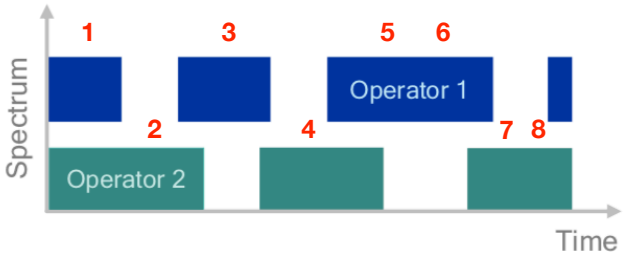


Dynamic vertical sharing

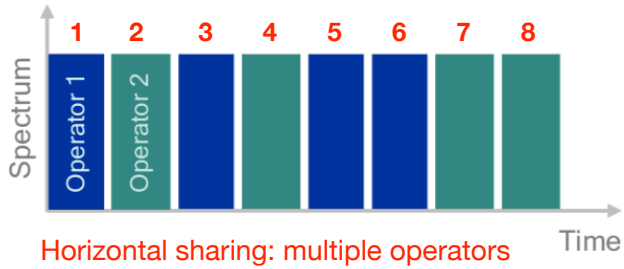


Vertical sharing: multiple operators at different priority, higher tier not interfered by lower ones

Static allocation

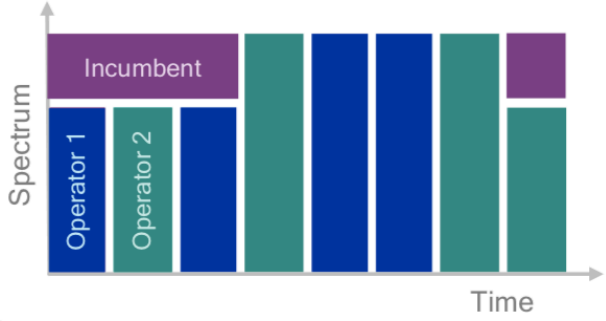


Dynamic horizontal sharing



Horizontal sharing: multiple operators sharing the spectrum with the same priority

Dynamic combined sharing

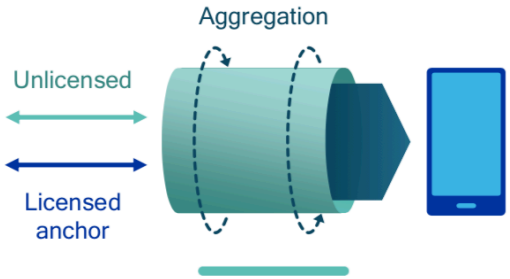


Combined sharing: vertical sharing plus horizontal sharing in at least one of the tiers

Spectrum not fully utilized → Increased spectrum utilization

3GPP Study on 5G NR Operation in Unlicensed Spectrum

First time 3GPP studies cellular technology operating stand-alone in unlicensed[1]

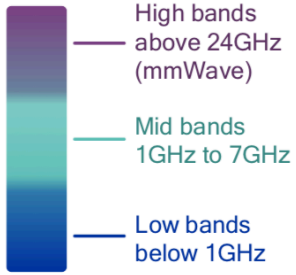


NR-based LAA

NR in unlicensed aggregated with LTE (dual-connectivity) or NR (carrier-aggregation) in licensed spectrum

Stand-alone unlicensed

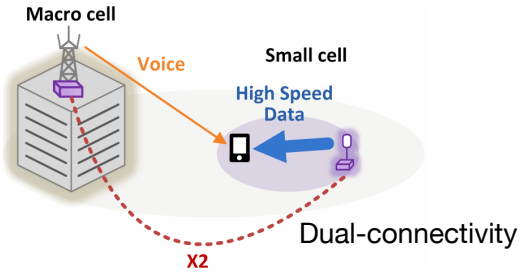
NR operating standalone in unlicensed spectrum. This will become the MulteFire™ evolution path to 5G



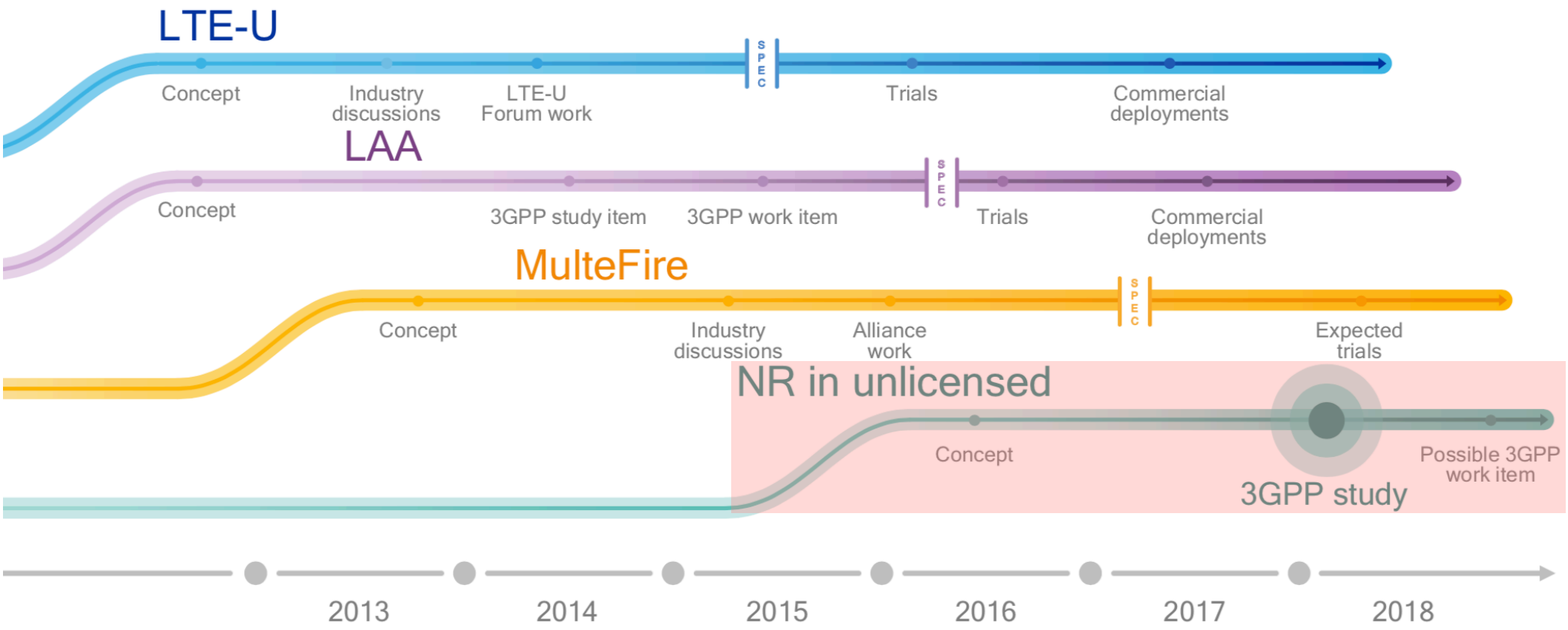
Across spectrum bands

Both below and above 6 GHz, e.g., 5GHz, 37GHz, 60GHz* (*assuming no change to waveform)

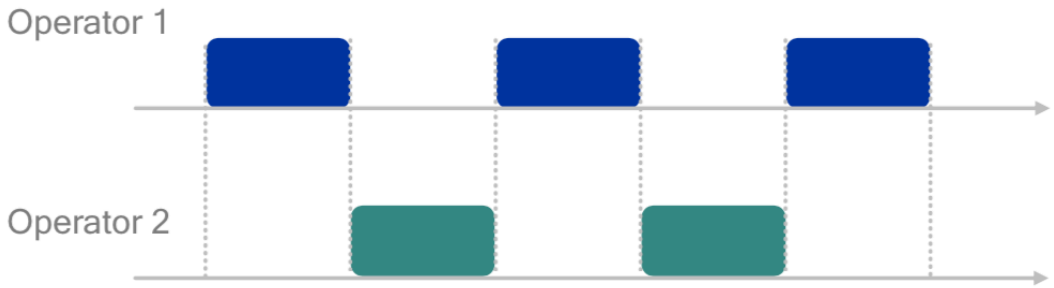
Fair co-existence in any unlicensed spectrum: NR/NR, NR/LTE, NR/Wi-Fi



Many Years in Making to Lead Up to NR in Unlicensed



Opportunity to Introduce a Revolutionary Path



Evolution path, incremental gains

- Existing unlicensed spectrum
- Backwards compatible and fair co-existence with Wi-Fi, LAA, MulteFire
- Introduce principles from LAA and MulteFire to NR framework (e.g., wideband channels, advanced coding…)
- Uncoordinated sharing
- Incremental enhancements

Revolution path, significant gains

- Green-field shared/unlicensed spectrum
- Opportunity to introduce new sharing paradigms
- Introduce time synchronization between operators (over-the-air or via network functionality)
- Coordinated sharing
- Significant performance gains

What is Revolutionary from Previous Sharing Solutions?

New sharing paradigms

New 5G NR framework is friendly for efficient sharing from the beginning

Coordination and time synchronization among sharing entities to improve efficiency and robustness

Elevate support of guaranteed QoS services when sharing spectrum and greatly improve upon simple best-effort practice

Exploit spatial domain: High frequency bands and MIMO with many antennas naturally suitable for sharing and CoMP

Support flexible spectrum sharing, both vertical and horizontal spectrum sharing

Flexible NR Framework Supports New Sharing Paradigms

Building on spectrum sharing technologies that we are pioneering today for LTE

Today's spectrum sharing technologies

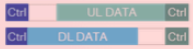
- LTE-U / LAA
- LWA
- MulteFire
- CBRS / LSA

Introducing new sharing paradigms

NR-SS[1]

Flexible NR framework

- Flexible slot-based framework
- Scalable OFDM-based air interface
- Network MIMO
- TDD self-contained slot structure



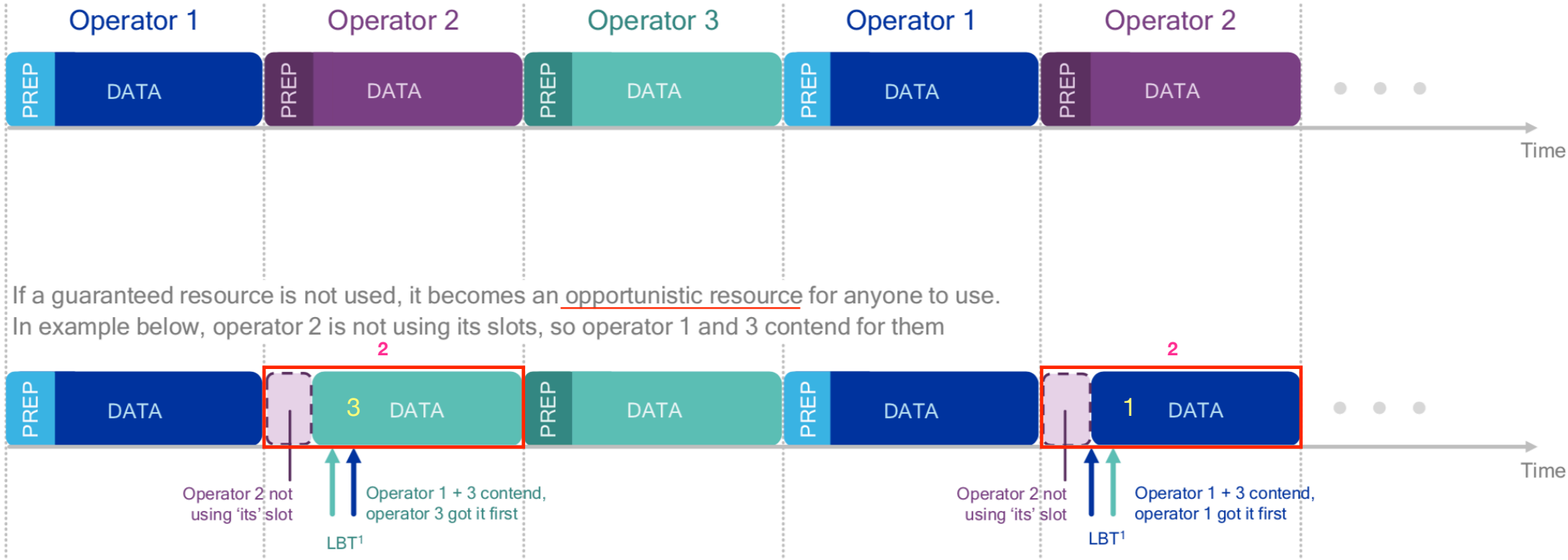
- Mobile mmWave

NR-SS：5G NR Spectrum Sharing

Guaranteed Resources with Opportunistic Sharing

A new sharing paradigm enabled by time-synchronization

Each operator gets guaranteed resources in time in a rotating fashion, example below with 3 operators

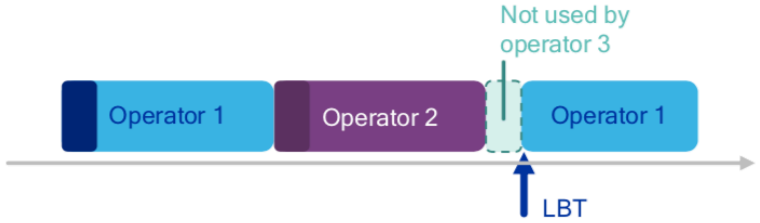


If a guaranteed resource is not used, it becomes an opportunistic resource for anyone to use.
In example below, operator 2 is not using its slots, so operator 1 and 3 contend for them

Support both Horizontal and Vertical Sharing

Horizontal sharing

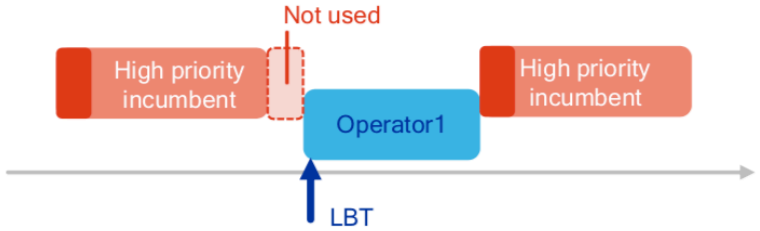
Multiple operators sharing the spectrum with the same priority



Rotating between guaranteed resources. If not used, becomes opportunistic resources

Vertical sharing

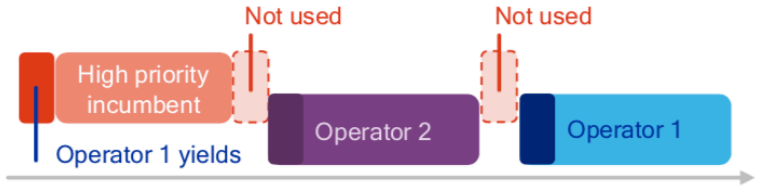
Multiple operators at different priority; higher tier not interfered by lower ones



Priority tier: Always guaranteed resources. Lower tiers: Always opportunistic resources

Combined sharing

Vertical sharing plus horizontal sharing in at least one of the tiers

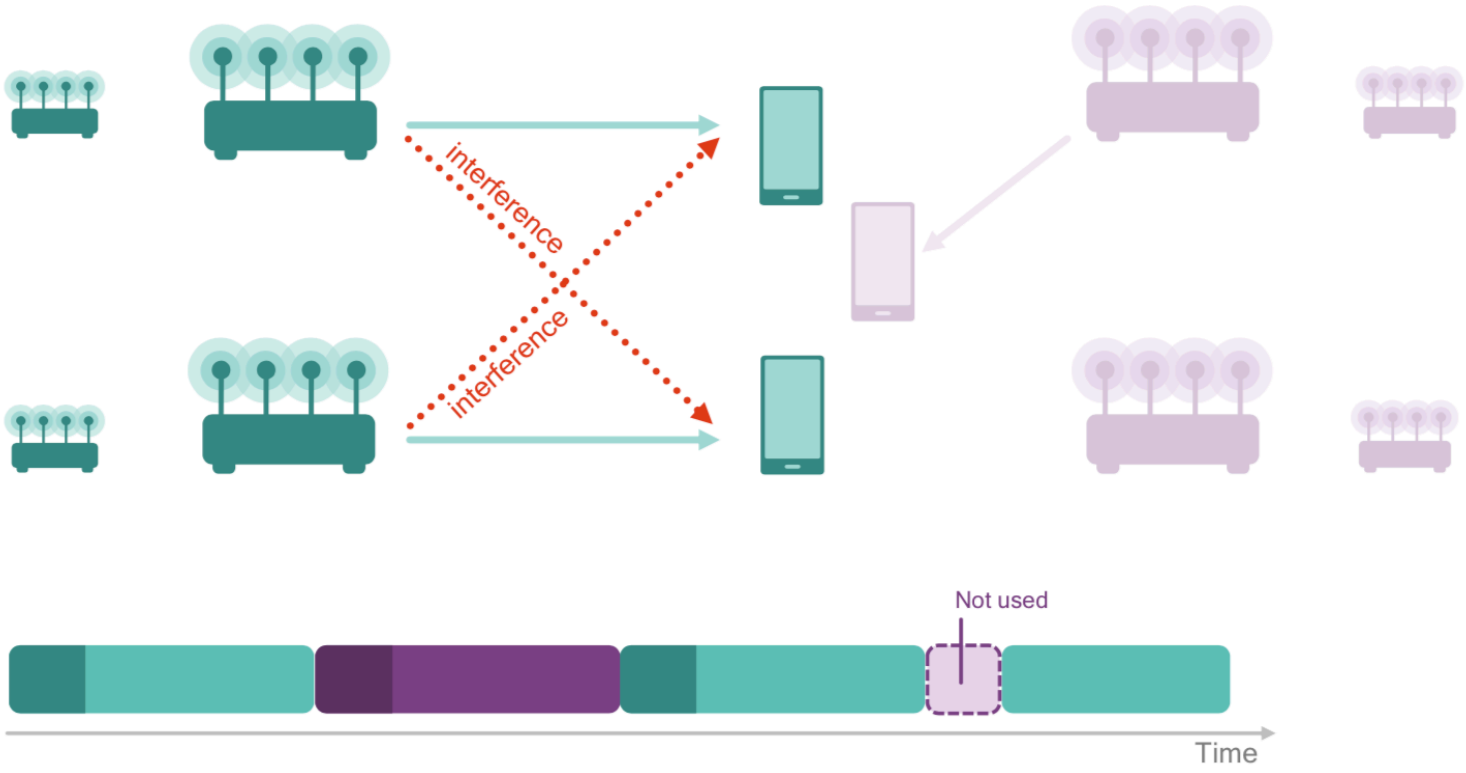


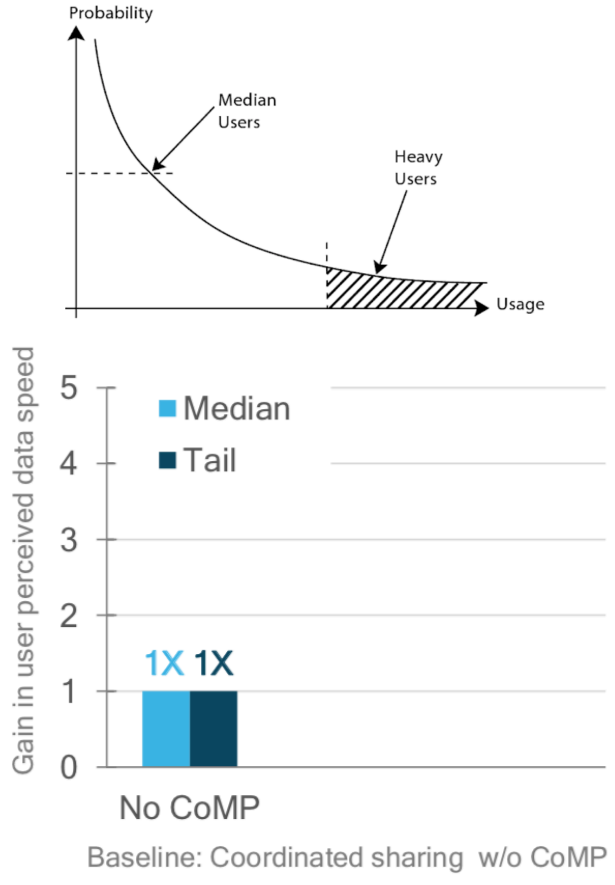
Channel reservation signaling can support multiple operators, e.g., high priority and rotating guaranteed resources.

CoMP Provides Significant Gains

Network MIMO with large number of antennas serve as foundation for CoMP

Two operators sharing spectrum

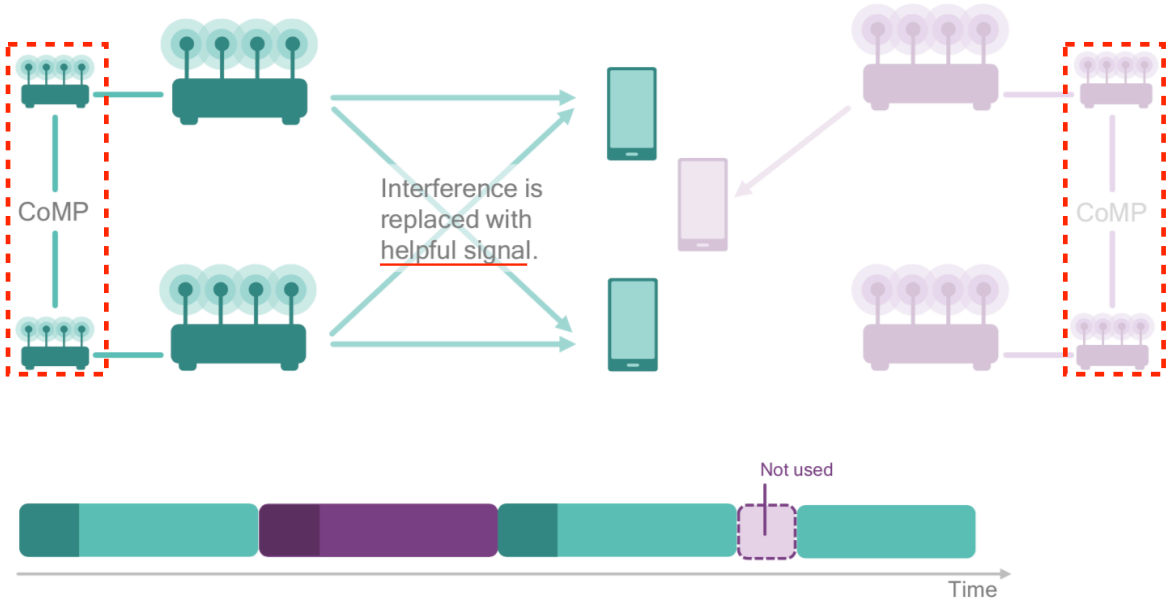




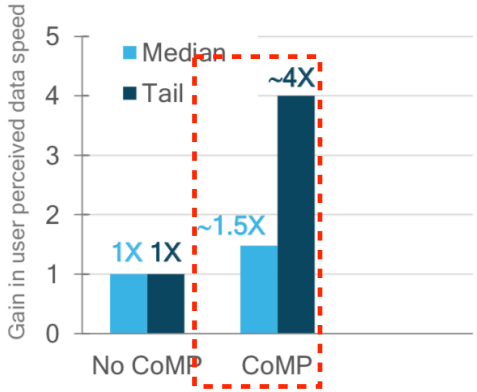
CoMP：Coordinated MultiPoint

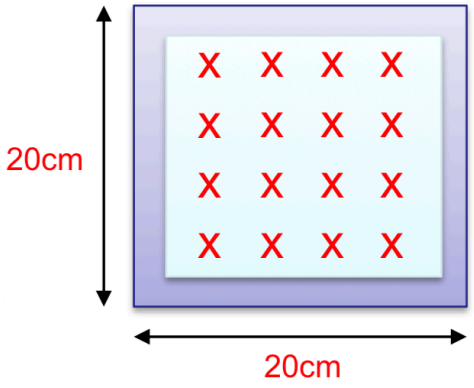
Network MIMO with large number of antennas serve as foundation for CoMP

Two operators sharing spectrum with intra-operator CoMP



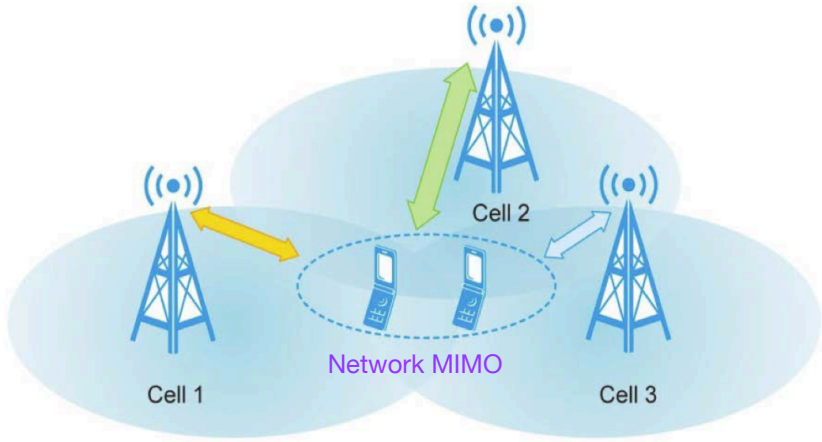
Significant gains in user data speeds, both for median and tail users





3.5GHz
Antenna spacing
0.5 wavelength
16 antennas

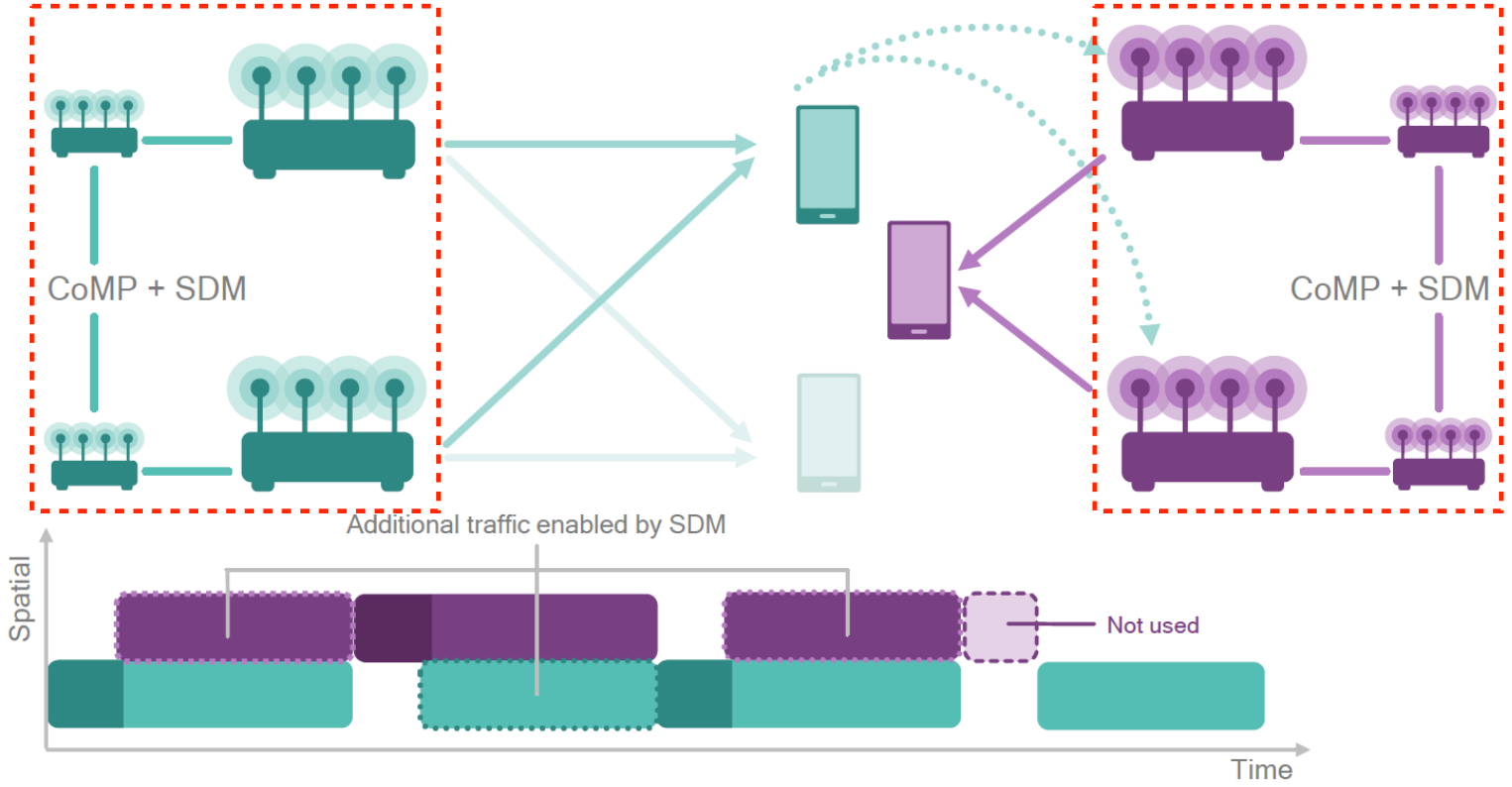
Massive MIMO



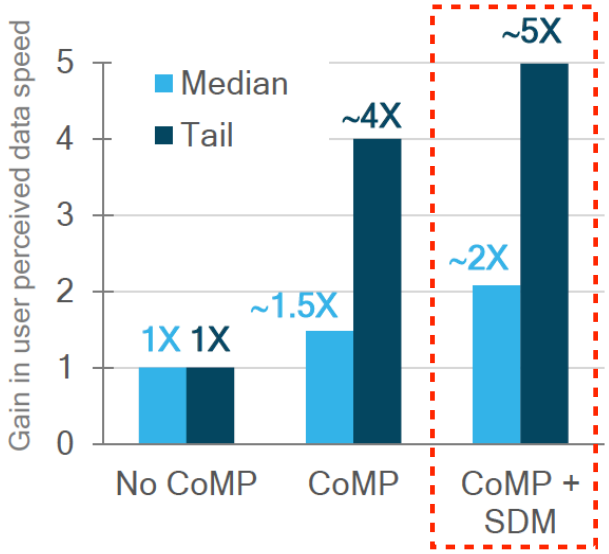
Extending CoMP with Spatial Division Multiplexing (SDM)

With time-synchronization, operators can opportunistically share spectrum spatially

Intra-operator CoMP with inter-operator SDM

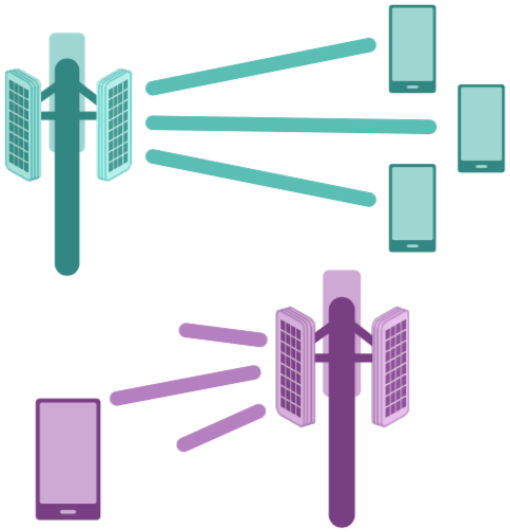


SDM provides additional gains that grows with number of operators

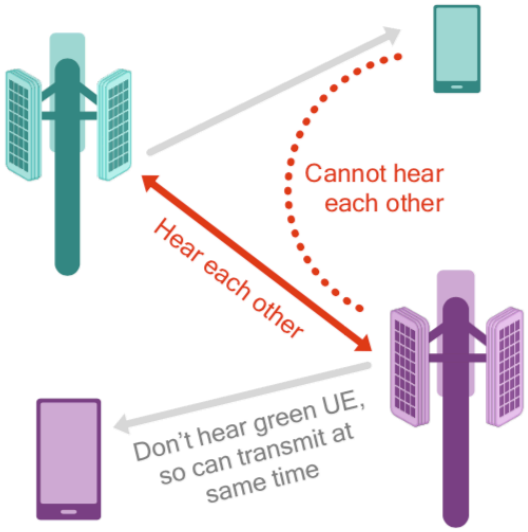


Additional Opportunistic Spatial Sharing

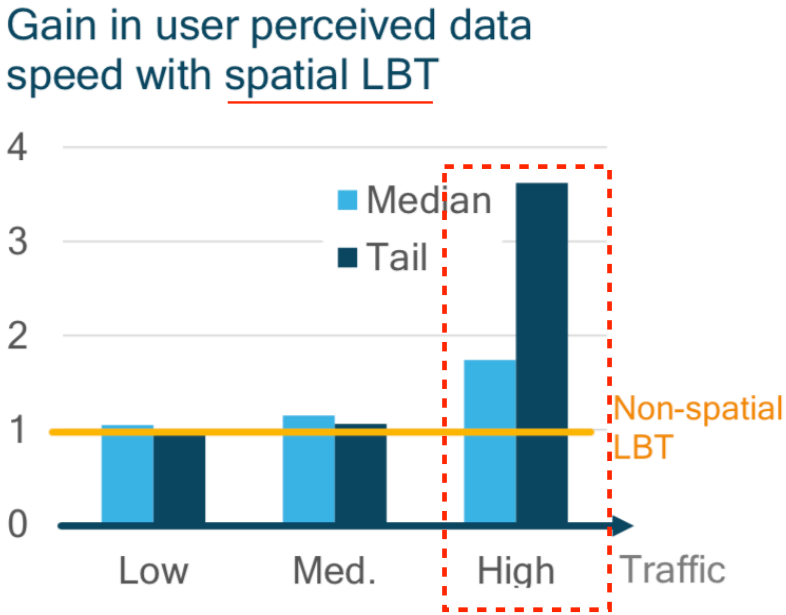
More antennas enable spatial LBT for directional channel sensing and reservation



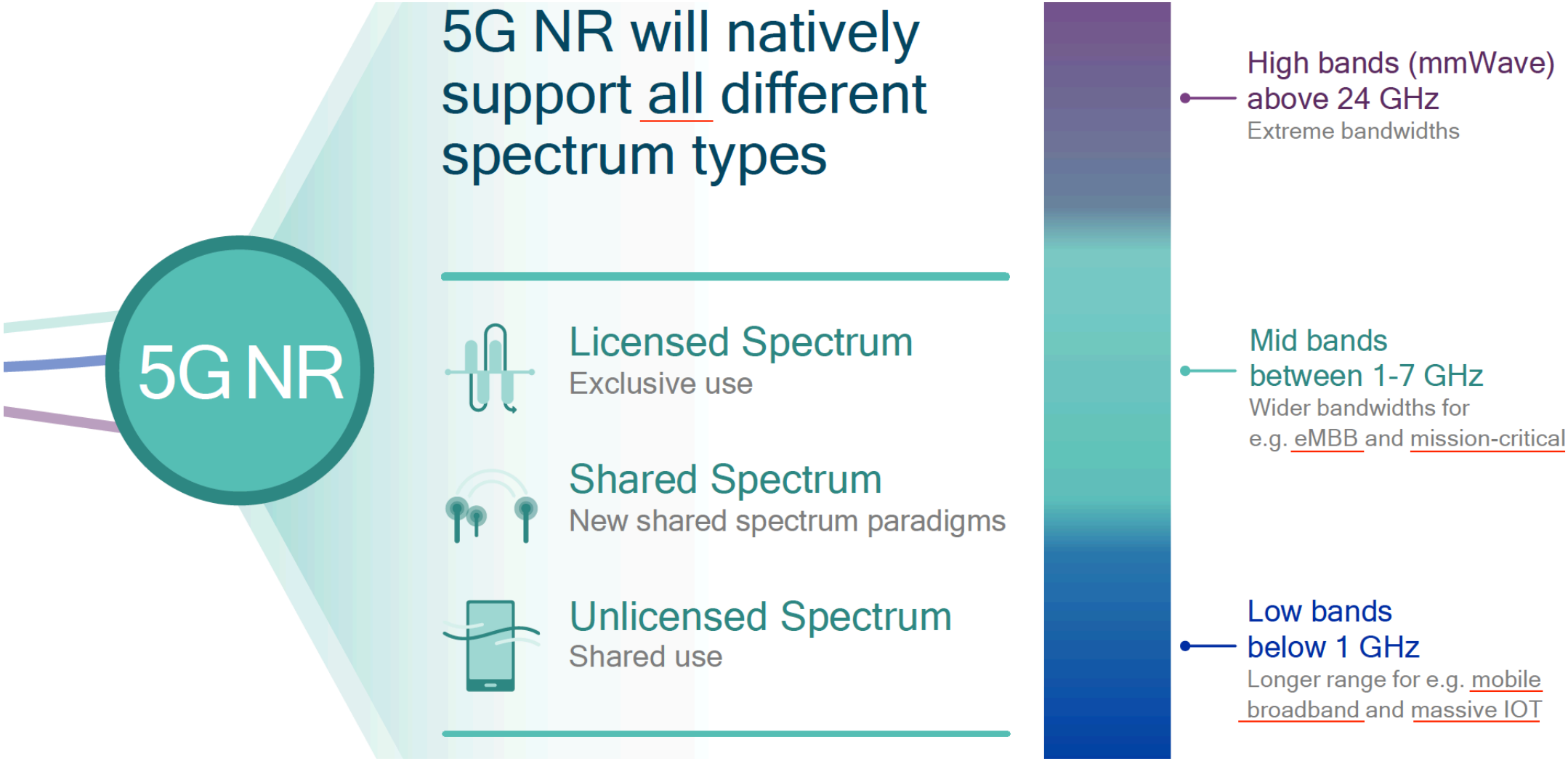
With more antennas, links becomes more directional and less likely to interfere



With directional links the interference dynamics are different at transmitter and receiver



Spatial LBT provides significant performance gains as traffic load increases[1]


5G NR will natively support all different spectrum types
5G NR
Licensed Spectrum
Exclusive use
Shared Spectrum
New shared spectrum paradigms
Unlicensed Spectrum
Shared use
High bands (mmWave) above 24 GHz
Extreme bandwidths
Mid bands between 1-7 GHz
Wider bandwidths for e.g. eMBB and mission-critical
Low bands below 1 GHz
Longer range for e.g. mobile broadband and massive IOT