Shared Access to Spectrum in Wireless Networks: Challenges and Opportunities

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Agenda

- Shared Spectrum is Require: Dramatic Rise in Mobile Use
- Shared Access to Spectrum: Different Models
- Shared Access to Spectrum: Coexistence Management
Shared Spectrum is Require: Dramatic Rise in Mobile Use
Dramatic Rise in Wireless Data Consumption

Even faster growth in the next decade

**Richer content**
- More video

Bestseller example:
- 5.93 GB Movie (High Definition)
- 2.49 GB Movie (Standard Definition)
- 0.0014 GB Homepage
- 1.8 GB Game for Android
- 0.14 GB Soundtrack
- 0.00091 GB Book

**More devices**
- Everything connected

- ~25 Billion Interconnected device forecast in 2020
- ~7 Billion Cumulative smartphone forecast between 2013-2017

All techniques, and all frequency bands must be used to meet the need!

*1000x would be e.g. reached if mobile data traffic doubled ten times, but Qualcomm does not make predictions when 1000x will happen. Qualcomm work on the solutions to enable 1000x.
(Dramatic?) Measures to Increase Capacity

- More spectrum allocation (higher bps)
  - Flexible bandwidth, spectrum aggregation, supplementary downlink,

- Improved spectral efficiency (higher bps/Hz)
  - Air interface evolution (different MIMO versions, high level modulation), interference management/Self Organizing Networks

- Network densification / Intelligent access to 3G/4G/RLAN (higher bps/ Hz/km2)
  - HetNet, small cells – everywhere

- Key measures are network densification and spectrum allocation
  - Physical limits of network densification and improved spectral to cater for data growth
    - Need for enormous spectrum allocation

- An approach only based on clearing spectrum for exclusive use, most likely very difficult even within a reasonable time frame

Need for multiple approaches to access more spectrum
We Need to Make Best Use of all Spectrum Types for 1000x

**Licensed Spectrum**
Auctions of cleared spectrum for 3G/4G

**Shared Licensed Spectrum**
Complementary licensing for 3G/4G: Licensed Shared Access (LSA)

**Unlicensed Spectrum**
Multiple technologies (Wi-Fi, LTE in Unlicensed, BT & others)

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**Exclusive use**
Industry's top priority, ensures quality of service (QoS), mobility and control

**Shared exclusive use**
ASA required when government spectrum cannot be cleared within a reasonable timeframe, or at all locations

**Shared use**
Unpredictable QoS, ideal for local area access, and opportunistic use for mobile broadband
Shared Access to Spectrum: Different Models
Model 1: LTE Licensed Shared Access to Spectrum

**Exclusive use**
- At given locations/times ensures predictability for long-term investments
- LSA target bands:
  - Already globally allocated to IMT but not cleared due to incumbents
  - No device impact, just regular 3G/4G devices supporting globally harmonized band

**Protect incumbents**
- Binary use: either incumbent or operator
- Protection zones required
  - The higher frequency range, the smaller protection distance

**Optimal for small cells**
- Small cells can be closer to incumbent than macros
  - Higher frequency ranges optimal targets for ASA, e.g. 2.3 GHz, 3.5 GHz
# Licensed Harmonized Spectrum

Leveraging global, available 4G technologies to ensure economies of scale

<table>
<thead>
<tr>
<th>LSA CANDIDATES</th>
<th>2.3 GHz (100 MHz)</th>
<th>2.6 GHz (100+ MHz)</th>
<th>~3.5 GHz (100-150 MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applicable Regions</strong></td>
<td>EUROPE (Traditionally licensed in e.g. India)</td>
<td>MENA (Traditionally licensed in e.g. Europe)</td>
<td>USA, EU, LATAM, SEAP</td>
</tr>
<tr>
<td><strong>Incumbent Users</strong></td>
<td>Telemetry, public safety, cameras</td>
<td>Various</td>
<td>Naval Radar (US) Satellite (EU, LATAM, SEAP)</td>
</tr>
<tr>
<td><strong>Suitable Technology</strong></td>
<td>LTE TDD</td>
<td>LTE FDD/TDD</td>
<td>LTE TDD</td>
</tr>
<tr>
<td><strong>Possible Launch</strong></td>
<td>~2015</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3.4-3.8 GHz

- 3GPP has already defined bands 42/43 for 3.4 GHz to 3.8 GHz, 3.5GHz in the US defined as 3550 – 3650 MHz, but up to 200MHz could be targeted for LSA in e.g. SEAP/LATAM. Note that LSA targets IMT spectrum bands, but the concept can be applied generally to all spectrum bands and other technologies.

### 2.3-2.4 GHz

- Various

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LSA\textsuperscript{1} Implementation Underway in Europe and USA

**POLICY**

- **Endorsed** by 28 EU member states Nov '13
- **Evaluation by NTIA**
  - Endorsed by 28 EU member states Nov '13

**REGULATORY**

- ** Defined by CEPT** in report published in Feb '14\textsuperscript{2} for harmonizing 2.3 GHz\textsuperscript{3}
- **Proposed by FCC**
  - To make 3.5GHz\textsuperscript{4} band dedicated to licensed shared access for mobile broadband

**STANDARDS**

- **Specified by ETSI** Currently working on requirements
- **Demonstrated by many infra/device vendors; 2.3 GHz and 3.5 GHz demos at MWC Feb '14**

**PROOF OF CONCEPT**

- **Trialed Live in Finland in Sep’13**

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\textsuperscript{1} LSA (Licensed Shared Access) in the EU by the Radio Spectrum Policy Group; \textsuperscript{2}3ECC Report 205; \textsuperscript{3}Draft ECC decision on “harmonized technical and regulatory conditions for the use of the band 2300-2600 MHz for MFCN”; \textsuperscript{4}3GPP Band 40, 2.3-2.4 GHz; \textsuperscript{5} Target 3.5 GHz in the US is 3550-3650 MHz
3.5 GHz: Qualcomm Activities – 2012-14

- **Exclusion zone analysis (2012-13)**
  - Analyzed the exclusion zones using NTIA methodology (irregular terrain model)
  - LTE interference towards Ship-borne, air-borne and ground-based radar equipment
  - Showed that usage of LTE small cells reduces exclusion zones to 0-15 miles from coast
    - Documented in NPRM comments

- **LSA Standards (2013-14)**
  - Leading the standards effort in ETSI RRS (Reconfigurable Radio System) WG1

- **LSA demos (MWC 2014)**
  - 3.5 GHz ↔ Ericsson infrastructure plus Qualcomm devices, also shown at CTIA 2014
  - 2.3 GHz ↔ Nokia infrastructure plus Qualcomm devices

- **LTE-Radar lab tests with NTIA (2014)**
  - Analyzed impact of radar interference to LTE downlink and uplink using test equipment
Model 2: LTE Unlicensed Shared Access to Spectrum

**Better network performance**
- Longer range and increased capacity\(^1\)

**Unified LTE Network**
- Common LTE network with common authentication, security and management.

**Enhanced user experience**
- Thanks to LTE Advanced anchor in licensed spectrum with robust mobility

**Coexists with Wi-Fi**
- Features to protect Wi-Fi neighbors

Extending the benefits of LTE Advanced to unlicensed spectrum (LTE-U)

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\(^1\) Compared to carrier Wi-Fi
Target Unlicensed Spectrum: 5 GHz UNII Bands

5 GHz band: ~500 MHz available; more possibly being added

- 5.15 GHz
- 5.25 GHz
- 5.35 GHz
- 5.47 GHz
- 5.85 GHz

US, Europe, Japan, India, China

US, Europe, Japan

US, India, China, considered in EU

In US, China and India, there is no specific waveform requirement other than RF

- In March 2014, US FCC relaxed the rules on 5150-5250MHz (UNII-1) allowing outdoor usage and higher Tx power as that of 5725-5850MHz (UNII-3): 36dBm EIRP (30dBm Tx power + 6dBi antenna gain)

1 Feasibility studies directed by the Middle Class Relief & Job Creation Act of 2012.
2 Study of 5350MHz-5470MHz and 5725MHz-5925MHz use for license exempt is being planned in EU
LTE-U Carrier Aggregation Modes

LTE-U
Supplemental Downlink (SDL)

LTE-U
Carrier Aggregation (CA)
LTE-U Deployment Models

**LTE-U ideal for small cells**
- Outdoor picocells, metrocells
- Indoor small cells for enterprise and residential
- Possibly integrated with Wi-Fi

**Single LTE network for licensed and unlicensed**
- Integrated eNB
- Same core elements
- Same mobility and security framework
Expected LTE-U Performance in Dense Network

Wi-Fi performance as the baseline

Assumptions: Two operators, 48 Pico+108 Femto cells per operator, 300 users per operator with 70% indoor, 3GPP Bursty model, 12x40MHz @ 5GHz for unlicensed spectrum, LTE 10 MHz channel at 2 GHz, 2x2 MIMO for Wi-Fi, LTE and LTE in unlicensed phase II with Rank 1 transmission. eICIC enabled.
LTE-U and Wi-Fi use the same configuration: outdoor SC/AP 2Tx/2Rx same Tx power (20dBm), same antenna gain (2dBi), 20MHz bandwidth, UE/STA use 1Tx/2Rx, 5GHz. LTE-U uses TDD config 2 with no DL data on special SF (60% DL duty cycle). Wi-Fi supports 802.11g/n modes.

LTE-U Offers Better Coverage than Wi-Fi
Shared Access to Spectrum: Coexistence Management
Spectrum Sharing Mechanisms

- **Much easier for LSA operation**
  - Well defined regulatory framework
  - Binary use: either incumbent or operator in the case incumbent doesn’t utilize the spectrum
  - Criteria for protecting incumbent from interference pretty straightforward
  - Protection zones, non-overlapping time or frequency ranges
  - Quick and efficient remedy for interference
  - Well defined interfaces

- **More challenging for unlicensed operation (examples: ETSI ENs 301 893 and 300 328)**
  - Regulatory framework much more complex than LSA operation
  - Different systems might use very different mechanisms for accessing the medium
  - Binary use could be still a requirement, e.g. in the case of radar operation in 5 GHz (DFS requirement)
  - Criteria for coexistence less straightforward and depend on frequency bands, involved systems, etc.
  - Requirements on channel occupancy time and/or BW as well as transmit power and/or power spectral density
  - Less efficient and partly time-consuming remedy for interference
  - Standardized LBT and/or non-standards measures/implementation based on radio resource management
Case Study: LTE – WiFi Unlicensed Operation in 5GHz

- Certain regions only have Tx power / PSD and emissions requirements
  - US, Korea, China, India and other markets
  - In principle compatible with LTE Rel-10/11/12
  - New RF band support (e.g. 5GHz) needed at both UE and eNB
  - Coexistence and fair sharing between LTE-U and WiFi can be achieved by non-standards, radio resource management implementation

- Certain regions have additional channel occupancy requirements
  - Europe, Japan and other markets
  - LTE needs “Listen Before Talk” feature based on PHY/MAC enhancements
    - In Europe as defined in EN 302 893 v1.7.1
    - Target LTE Rel-13 and beyond

Coexistence and fair sharing with WiFi is a requirement for LTE-U in all regions
LTE-U is Designed to Coexists with Wi-Fi

1. **Dynamically select clear channel:** channel selection based on interference

   - Unlicensed 5 GHz band
   - Frequency:
     - 5.15 GHz
     - 5.33 GHz
     - 5.49 GHz
     - 5.835 GHz
   - Spectrum availability:
     - 20 MHz
     - Up to 500 MHz available

2. **Mitigate if no clear channel is available:** co-channel co-existence features

   - Adaptive on/off duty cycle with CSAT depending on channel utilization
   - Sensing channel availability
   - LTE is off
   - LTE is on
   - LTE is off
   - Time
   - Carrier Sensing Adaptive Transmission (CSAT) for fair co-existence with Wi-Fi with 3GPP R10/11/12 for non-LBT regions e.g. US, Korea, China.
   - Optimized LTE waveform for Listen-Before-Talk targeting 3GPP R13 to meet regulatory requirements for LBT regions e.g. EU, Japan

3. **Release unlicensed channel at low traffic load:** fall back to licensed spectrum operation only

   - Sensing channel availability
   - Time
   - ~2-10 ms with ‘Listen Before Talk’ features
   - ~100+ ms long gap
   - < 10 ms short gap
CCA period $\geq 20$ uS

Channel Occupancy Time: between 1 and 10 ms

Min idle period: 5% of occupancy ($\geq 50$ μs)

CCA threshold: $-73$ dBm/MHz + (23 – TxP)

(TxP: max EIRP)

Reference: ETSI EN 301 893 V1.7.1
LBT Specification for Load Based Equipment

Load Based Equipment not using any of the mechanisms referenced above shall comply with the following minimum set of requirements:

1) Before a transmission or a burst of transmissions on an Operating Channel, the equipment shall perform a Clear Channel Assessment (CCA) check using “energy detect”. The equipment shall observe the Operating Channel(s) for the duration of the CCA observation time which shall be not less than 20 µs. The CCA observation time used by the equipment shall be declared by the manufacturer. The Operating Channel shall be considered occupied if the energy level in the channel exceeds the threshold corresponding to the power level given in point 5 below. If the equipment finds the channel to be clear, it may transmit immediately (see point 3 below).

2) If the equipment finds an Operating Channel occupied, it shall not transmit in that channel. The equipment shall perform an Extended CCA check in which the Operating Channel is observed for the duration of a random factor N multiplied by the CCA observation time. N defines the number of clear idle slots resulting in a total Idle Period that need to be observed before initiation of the transmission. The value of N shall be randomly selected in the range 1..q every time an Extended CCA is required and the value stored in a counter. The value of q is selected by the manufacturer in the range 4..32. This selected value shall be declared by the manufacturer (see clause 5.3.1 q)). The counter is decremented every time a CCA slot is considered to be "unoccupied". When the counter reaches zero, the equipment may transmit.

NOTE 2: The equipment is allowed to continue Short Control Signalling Transmissions on this channel providing it complies with the requirements in clause 4.9.2.3.

NOTE 3: For equipment having simultaneous transmissions on multiple (adjacent or non-adjacent) operating channels, the equipment is allowed to continue transmissions on other Operating Channels providing the CCA check did not detect any signals on those channels.

3) The total time that an equipment makes use of an Operating Channel is the Maximum Channel Occupancy Time which shall be less than (13/32) × q ms, with q as defined in point 2 above, after which the device shall perform the Extended CCA described in point 2 above.

Reference: ETSI EN 301 893 V1.7.1

CCA threshold: -73 dBm/MHz + (23 − TnP)
(TnP: max EIRP)
Envisioned PHY/MAC Features for LTE-U to Accommodate LBT

| Discovery signals | • Needed to discover and acquire access  
|                   | • Multiple PLMNs |
| LBT using Clear Channel Assessment (CCA) | • Needed to meet regional requirements (Europe, Japan) |
| Beacon signals | • To reserve the channel for transmission following LBT |
| Modified DL & UL waveform | • Modified to enable LBT  
|                           | • UL modified to meet channel occupancy definition |
| Modified HARQ protocol | • Asynchronous HARQ design considering no guaranteed access to channel |