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I. SPECTRUM SHARING WORKING GROUP WORKING RECOMMENDATIONS

The CSMAC recommends that the NTIA:

1. Develop a set of spectrum sharing system requirements. The requirements are used to develop and to analyze spectrum sharing approaches. The requirements include general requirements for most spectrum bands and requirements for specific bands. The requirements include estimated limits on the changes in incumbent use (waveforms, locations, occupancy, etc). The NTIA should develop both incumbent and entrant requirements, assuming that in some cases the entrant systems may be other federal systems. The requirements should be made public and open for comment. Currently the requirements are not well known, which makes it difficult for incumbents and entrants to develop or analyze spectrum sharing approaches.

2. Require that a management and control (e.g., an interactive database) feature be used in all spectrum sharing approaches. The management and control feature is needed to supervise and reconfigure the entrant system. The management and control feature would have a defined reaction time (not necessarily continuously connected). The management and control feature would apply to geographic-based, to sensing-based, or to any other spectrum sharing approach.

3. Not select a certain spectrum sharing approach at this time. There are many potential spectrum sharing approaches that are capable of meeting the spectrum sharing requirements. The different approaches have their own costs, advantages and disadvantages that depend on the entrant and incumbent system details. Once the NTIA releases: (a) The requirements, and (b) More detailed information on the incumbent systems and the incumbent CONOPS, then these different sharing approaches can be evaluated by industry, and then specific proposals can be made to the NTIA. When analyzing alternate approaches, both the entrant and incumbent factors need to be considered in selecting the spectrum sharing approaches. It is likely that multiple spectrum sharing approaches will be used in a band to most economically accommodate the incumbent and entrant requirements. Selecting a spectrum sharing approach now is likely to result in a costly or an ineffective approach that will not ultimately be successful.
II. SPECTRUM SHARING REQUIREMENTS

These are the incumbent’s and the entrant’s requirements that different spectrum sharing approaches must meet.

1. Requirements of Incumbent

• Do No Harm to incumbent
• Accommodate Changes in Incumbent Use – Waveform types, occupancy, locations, etc
• Backup Band for entrant – Able reclaim the spectrum
• Enforcement – Track down interference events economically and quickly
• Safeguards/security – Protect against unauthorized and accidental use, avoid hackers
• DSA system diversity causing complexity – Many DSA types and entrants is too hard to manage
• Trust – Need assurance that agreement points will not change
• Security – Don’t want to reveal classified information

2. Requirements of Entrant

• Do No Harm to entrant – Concerns that incumbent will have unreasonable interference criteria. Concerns that the incumbent system receiver and other equipment characteristics are different than originally planned for.
• Safeguards/security – Protect against unauthorized and accidental use, avoid hackers
• Support current architecture (i.e. frequency duplex)
• Minimal changes to standards – Want to purchase standardized, non-proprietary equipment from multiple vendors
• Low prime power
• Minimal software integration costs
• Capacity – Minimal capacity lost with ‘Do No Harm’ or with fair use rules
• High reliability and assured access
• Reduce operator workload
• Trust – Need assurance that agreement points will not change
• Fair use policy
III. WHAT KINDS OF SHARING ARE WORKABLE FOR INDUSTRY IN THE LONG TERM?

1. Spectrum Sharing Method Alternatives

   a. Spectrum Sharing Mechanism

   • Geo-Location method used to determine the transceiver parameters/capabilities (e.g., transmits frequency and power level, bandwidth, receiver capabilities).
     o Exact position vs. approximate position
     o User entered position versus GPS position versus trusted source for position

   • Sensing-based method used to determine the transceiver parameters/capabilities.
     o Sensing on all entrant radios
     o Sensing on some entrant radios
     o Sensing at certain locations
     o External sensing network
     o Collaborative entrant sensing

   • Combined sensing and geo-location methods used to determine the transmitted transceiver parameters/capabilities.

   • Physical layer
     o Receiver ignores interference
     o Transmit modulation (UWB)

   • Timesharing
     o Entrant and Incumbent share information to share spectrum in time
     o Entrant senses channel and stops transmitting rapidly when the Incumbent begins transmitting, so as not to interfere with Incumbent communication

Example spectrum sharing architectures are shown below:
System #1 - Geo-location System
(Same As Time Sharing)

Features
• Incumbent agrees to continually provide approximate position and operating frequency (potentially in advance)
• Propagation model, antenna gain and antenna height assumptions
• Incumbent and entrant location accuracy
• Moderate spectrum availability (due to parameter uncertainties)

Factors
• Reduced spectrum availability (Incumbent position uncertainty)
• Number and cost of Dedicated Sensors (own operates and pays?)
• Propagation model, antenna gain and antenna height assumptions
• Entrant location accuracy
• Incumbent views system the same as geo-location system approach
System #4 – Sensing on All Entrant Radios System

Factors
- Sensing software integration costs into entrant equipment
- Maximum spectrum availability (minimal propagation loss uncertainties)
b. **Method Features**

- Database connected or un-tethered method used to manage the spectrum sharing method.
  - Applied to either geographic or sensing-based methods
  - Continuous connection
  - Occasional connection (i.e. like the FCC TV whitespace Geo-Location/Database approach)
  - Periodic connection (annual)
  - Provide rule set or provide list of operating frequencies or provide operating frequency

- **Interference Basis**
  - Entrant/incumbent isolation determined by interference to entrant
  - Entrant/incumbent isolation determined by interference to incumbent
  - Entrant/incumbent isolation determined by interference to entrant or incumbent
IV. SPECTRUM SHARING COSTS

Table 1 shows the different spectrum sharing requirements and the approach used to meet the requirement. Also shown are the costs for the incumbent, the entrant, and for either party to meet the requirement.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Approach Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do No Harm</td>
<td>Certain frequencies at certain locations/times are unavailable for entrant use.¹</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Implement sensing-based sharing approach</td>
<td>Implement dynamic network management</td>
</tr>
<tr>
<td></td>
<td>Implement geographic-based sharing approach</td>
<td>Modify equipment to implement sensing.</td>
</tr>
<tr>
<td></td>
<td>Implement physical layer-based sharing approach</td>
<td>Build and operate database system.</td>
</tr>
<tr>
<td>Do No Harm</td>
<td>Implement cooperative time sharing-based sharing approach</td>
<td>Modify equipment to implement position location and connection to database.</td>
</tr>
<tr>
<td>Do No Harm</td>
<td>Implement opportunistic time sharing-based sharing approach</td>
<td>Build and operate database system.</td>
</tr>
<tr>
<td>Accommodate Changes in Incumbent Use</td>
<td>Entrant equipment connected to a database.²</td>
<td>Build and operate database system.</td>
</tr>
<tr>
<td>Accommodate Changes in Incumbent Use</td>
<td>Sensing-based approaches must have a programmable detector/classifier</td>
<td>Implement flexible, re-programmable detector/classifier.</td>
</tr>
<tr>
<td>Enforcement</td>
<td>Implement mechanism to detect and mitigate interference cause.</td>
<td>Operate interference management service.</td>
</tr>
<tr>
<td>Backup Band</td>
<td>Entrant hardware must cover multiple spectrum bands.</td>
<td>Additional hardware cost to cover additional spectrum bands.</td>
</tr>
<tr>
<td>Backup Band</td>
<td>Extra entrant spectrum must be</td>
<td>Potentially need to acquire</td>
</tr>
</tbody>
</table>

¹ Changes to the available frequencies are potentially dynamic ("cooperative time-sharing," and "opportunistic time-sharing"). The changes may be pre-planned (i.e. 24 hours notice by incumbent and then managed with a database) or may be sudden (i.e. no notice via unplanned incumbent usage change and then managed by a spectrum sensing mechanism).

² Used for all spectrum sharing mechanisms (geolocation, sensing, physical layer and time sharing).
| Safeguards / Security | Implement secure method to manage entrant spectrum. | None | Minimal cost, COTS solutions. | None |
V. ACCOMMODATING CHANGES IN INCUMBENT USE

Table 2 shows how different incumbent changes in use impact geo-location and sensing-based spectrum sharing mechanisms. Also shown are methods that could be used to reduce this impact and to provide certainty to the entrant. Relative difficulty to implement is shown (1-easy to 3-hard).

<table>
<thead>
<tr>
<th>Incumbent Change in Use</th>
<th>Impact to Geolocation-Based Entrant Only</th>
<th>Impact to Sensing-Based Entrant Only</th>
<th>Impact to Both Entrant Types</th>
<th>Method to Provide Certainty to Entrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waveform Type - modulation type, signal bandwidth or MAC</td>
<td>None</td>
<td>Must have enough waveform information to design classifier(3)</td>
<td>None</td>
<td>To enable sensing approach classifier design relative to entrant waveform, incumbent provides waveform information to limit waveform parameters.</td>
</tr>
<tr>
<td>Mix Waveform Types Within a Band</td>
<td>Adjust exclusion zone(1)</td>
<td>Implement multi-detector/classifier system(2)</td>
<td>None</td>
<td>Incumbent provides waveform types in the band</td>
</tr>
<tr>
<td>Withhold Transceiver Location Information</td>
<td>Approach not feasible(3)</td>
<td>None</td>
<td>None</td>
<td>Incumbent agrees to not change Transceiver Location Information policy</td>
</tr>
<tr>
<td>Provide Entrant Advanced Warning of Transceiver Operation</td>
<td>Assume 100% duty cycle and reduces amount of available spectrum, (2)</td>
<td>None</td>
<td>None</td>
<td>Incumbent agrees to not change advanced warning plan.</td>
</tr>
<tr>
<td>Mobility - Fixed to mobile to airborne transmitters</td>
<td>Obtain real-time transceiver location information, use large exclusion zones, or approach not feasible(3)</td>
<td>None</td>
<td>None</td>
<td>Incumbent agrees to not change mobility, or to provide transceivers info in real-time to enable geolocation approach.</td>
</tr>
<tr>
<td>Link Type – Duplex vs telemetry vs f1/f2</td>
<td>Adjust exclusion zone size(1)</td>
<td>Telemetry links require lower detection thresholds and reduces amount of available of spectrum. f1/f2 requires frequency plan information,(3)</td>
<td>None</td>
<td>Incumbent agrees to provide link type information.</td>
</tr>
<tr>
<td>Transmit Power Level</td>
<td>None</td>
<td>Change detection thresholds(1)</td>
<td>Decreases amount of available spectrum if sharing based on interference to entrant.</td>
<td>Incumbent agrees to limiting min and max transmit power level.</td>
</tr>
<tr>
<td>Transmit Mask Shape</td>
<td>Adjust exclusion zone if based on entrant interference(1)</td>
<td>Change detection thresholds(1)</td>
<td>Decreases amount of available spectrum if sharing based on interference to entrant.</td>
<td>Incumbent agrees to limiting min and max transmit mask.</td>
</tr>
<tr>
<td>Desired Interference To Noise Level</td>
<td>Adjust exclusion zone size(1)</td>
<td>Change detection thresholds (1)</td>
<td>Decreases amount of available spectrum.</td>
<td>Incumbent agrees to limiting interference level.</td>
</tr>
<tr>
<td>Number of transceivers or TX duty cycle</td>
<td>Provide waveform information and equipment description.(1)</td>
<td>None</td>
<td>Decreases amount of available spectrum</td>
<td>Incumbent agrees to limiting number of TX duty cycle within each operating area.</td>
</tr>
<tr>
<td>Receiver</td>
<td>Adjust exclusion</td>
<td>Change detection</td>
<td>Decreases amount of available spectrum</td>
<td>Incumbent agrees to limiting</td>
</tr>
<tr>
<td>Selectivity</td>
<td>zone size(1)</td>
<td>thresholds(1)</td>
<td>spectrum</td>
<td>adjacent channel rejection level</td>
</tr>
<tr>
<td>---------------------------------</td>
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<td>-----------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Antenna heights or antenna gain</td>
<td>Adjust exclusion</td>
<td>None</td>
<td>Decreases amount of available spectrum</td>
<td>Incumbent agrees to limiting</td>
</tr>
<tr>
<td>values</td>
<td>zone size(1)</td>
<td></td>
<td></td>
<td>antenna height.</td>
</tr>
</tbody>
</table>