Dynamic Spectrum Sharing
Lecture overview

This lecture focuses on concepts and algorithms for dynamically sharing the spectrum between licensed and unlicensed users.
Spectrum Scarcity
(hardly any spectrum left that is not allocated yet)
Spectrum and Mobile Industry

- To meet the rising demand for mobile communications, we need steady supply of spectrum.
- The usable spectrum is saturating fast.
- Spectrum scarcity may limit the growth of mobile industry.
Recent discovery of spectrum utilization

- Recent field measurements have shown that licensed spectrum remains largely underutilised!
- Underutilisation happens in both spatial and temporal dimensions
- For example, only 13% of total spectrum from 30MHz to 3GHz were found utilised in New York City (87% were not utilised)
- Spectrum scarcity, therefore, is an “artificial problem” caused by the existing method of spectrum regulation (i.e., once licensed, no one else can use it even when it is not used by the licensed user)
- Can we allow unlicensed users to use under-utilised licensed bands dynamically when and where licensed users are absent?
Lecture contents

- Candidate licensed bands for dynamic sharing
- Dynamic spectrum sharing framework
  - Spectrum sensing
  - Cognitive radio
- New standards
  - IEEE 802.11h (wifi sharing radar bands)
  - IEEE 802.22 or WRAN (wireless broadband sharing TV bands)
Candidate licensed bands

- Licensed bands that are significantly underutilised are good candidates for dynamic spectrum sharing
- Three major candidates are
  - Radar
  - TV
  - Cellular
Radar bands

- Radars are object detection systems
  - Aeronautical, maritime, weather, radiolocation

- Occupies a significant portion of spectrum
  - L band (960-1400 MHz), S band (2.7-3.6GHz), C band (5-5.85 GHz)

- These bands are good candidates for mobile data communications
  - Does not need too high power or directional antenna
  - Close to wifi and cellular bands (easy to share using low-cost radio hardware)
Spatial sharing of radar bands

- Radar stations are usually fixed at known locations and their transmission power, frequency are also known.
- It is therefore possible to work out the locations where radar bands can be shared safely by other non-licensed devices without interfering with radar systems.
- One caveat with spatial sharing: if radars are heavily deployed where humans live, it would limit the spectrum sharing opportunity.
  - Radars are heavily deployed in coastal areas blocking a large percentage of population from accessing it.
Temporal sharing of radar bands

- Radars use highly directional rotating antennas with predefined sweep patterns
- Opens up opportunity for temporal sharing
- Unlicensed device can share the spectrum when the radar is pointing in another direction
- Leads to some periodic spectrum sharing opportunity
Due to digitisation of TV broadcast, there is a large number of broadcasting channels available in the same licensed band.

Not all channels are used in all regions all the time.

White Space = unused spectrum in the TV band.

White space bands: VHF (54-216 MHz), UHF (470-790 MHz).

Long distance propagation without line-of-sight makes this band highly attractive for wireless data communication.

Suitable communication services are: wireless broadband, machine to machine communications, enhanced wifi etc.

TV station locations and their channel usage plans are publicly known making it easy to deploy spectrum sharing at specific regions.
Cellular bands

- Low utilisation in rural areas (spatial opportunity) and during night times (temporal opportunity)
- Also, the uplink bands are sometimes heavily underutilised (due to asymmetry in Internet upload/download)
- Spectrum sharing among operators is therefore an attractive solution to the rising cost of spectrum to support the ever growing demand for mobile communication
- However, unlike radar and TV, cellular traffic is highly unpredictable, making it relatively more challenging to share spectrum
Dynamic spectrum sharing framework

- **Primary user (PU)** is the user with the license to use the spectrum.
- **Secondary user (SU)** is the unlicensed user trying to opportunistically access the licensed band when it is not used by the primary user.
- **SU’s radio** must have the following **spectrum sensing capabilities**:
  - Start using a licensed channel only if PU is absent, vacate the channel immediately if PU is detected.
- **These intelligent radios** are called **cognitive radios**.
Cognitive radio

- The cognitive radio (CR) has the intelligence to scan a licensed channel and detect the presence/absence of PUs in the channel
- CR allows automatic and dynamic sharing of spectrum between licensed and non-licensed devices (no human intervention required)
IEEE 802.11h
(wifi sharing radar bands)
Spectrum crisis for wifi

- Wifi was originally designed to operate in the unlicensed ISM band of 2.4 GHz
- The rising popularity of wifi lead to dense deployment of wifi APs in most urban environments
- To meet the growing demand of wifi, more spectrum would be needed
- Dynamic spectrum sharing is one option
  - Allow wifi to opportunistically use some licensed bands using the concept of CR
A CR wifi that shares the radar band

The wifi radio has hardware to operate in both 2.4GHz (unlicensed ISM band) and 5GHz (licensed radar band)
- Often called dual-band wifi

5GHz band is divided into 15 channels (Channel #52-140)
- The wifi operates in any ONE of these channels at any time depending on the availability

Dynamically switching to any of these 15 channels is called Dynamic Frequency Selection (DFS)
### 802.11h DFS channels
*(source: CISCO)*

<table>
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<tr>
<th>Channel</th>
<th>Frequency (MHz)</th>
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<tbody>
<tr>
<td>52</td>
<td>5260</td>
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<tr>
<td>56</td>
<td>5280</td>
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<td>5300</td>
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<tr>
<td>140</td>
<td>5700</td>
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</tbody>
</table>
DFS operation

- **Channel availability check (CAC)**
  - AP randomly selects one of the 15 channels and scans the selected channel for 60 seconds
  - If radar is detected on this channel, mark the channel as 'radar channel' and avoid using this channel for 30 minutes (30-minute timer); select another channel randomly for scanning
  - If no radar detected in the scanned channel, it starts operating on this channel (starts sending beacons and accepting client associations)

- **Channel monitoring**
  - AP monitors its operating frequency (channel) for presence of radar
  - If radar detected, disassociate all clients, randomly select another channel not marked as 'radar channel' for scanning and CAC
Channel monitoring by clients

- By default, only the AP monitors the operating channel for radar detection; clients are not required to detect radar
- Wifi can be configured to operate in 'radar detection by client mode'
  - Client monitors the operating channel for radar
  - If radar is detected, it notifies the AP (AP may not have detected it due to positioned in a different location and presence of obstacles)
  - If the client is associated (authenticated), the AP switches channel using CAC, otherwise the notification is ignored

- Channel monitoring by clients is a form of cooperative spectrum sensing
Cooperative spectrum sensing

- Hidden terminal problem makes it difficult to guarantee PU detection
  - A PU is present in the channel, but not detected
- This can happen when the CR is shadowed
  - There is an obstacle between PU and CR preventing the signals from the PU to reach the CR in full force
- Cooperation between multiple CR distributed in space can help address the hidden node problem
- A CR fusion centre (BS) collects observations from multiple CRs and makes a decision based on some fusion rules
IEEE 802.22
(wireless broadband sharing TV bands)
Wired broadband is costly for rural deployments (does not have the population density to make it cost effective)

Wireless broadband would be more appropriate (easy to deploy), but requires access to spectrum

TV bands are highly underutilised in rural areas (not too many active channels and low density users)

A perfect case for building a rural wireless broadband service sharing TV bands

802.22 is a new CR-based standard to realise this vision
- http://www.ieee802.org/22/
802.22 needs the services of a spectrum database

An 802.22 wireless device must query the database for available channels (it includes its location in the query)

The database responds with a list of available white space channels based on the location of the wireless device

The database is built based on "contour" calculations using official data of each registered TV stations in the region

See Google for example
http://www.google.org/spectrum/whitespace/channel/

Channel availability check in 802.22 is done via database query instead of channel scanning
More WS availability in rural areas than city centres (green means 11 channels, red=4, purple = 1)

Spectrum availability (as of January 29, 2013)