Cognitive TD-LTE System Operating in TV White Space in China

Challenges, Solutions and Testbed

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Outline

❖ Background

❖ Challenges and Solutions in Cognitive TD-LTE System
  ▪ Cognitive Ability
  ▪ Autonomous Decision Making
  ▪ Adaptive Reconfiguration Ability

❖ Testbed for Cognitive TD-LTE System
Spectrum Shortage

- Existing bands have been exhausted
- There is a growing demand on spectrum resource due to the increasing demand on wireless transmission.
- The importance and scarcity of spectrum have become increasingly prominent.

Spectrum Waste

- TV white space is insufficiently used
- Field test of spectrum occupation at BUPT campus in China shows that spectrum efficiency is less than 5%, surprisingly similar to the data released by FCC.
- Spectrum is insufficiently used in both time and frequency.

Current spectrum usage is experiencing coexistence of spectrum shortage and waste.
How to efficiently utilize the vacant spectrum resource

- Requirement 1: Flexible transmission bandwidth
- Requirement 2: Dynamic spectrum management

Solution: Cognitive Radio System!

Why operate cognitive TD-LTE system in TV White Space

- Network Selection: Cellular Network
  - Cellular network is the pillar of telecommunication industry. Utilizing cognitive technology to solve spectrum usage in cellular network is of great importance.

- Mode selection: TD-LTE
  - Broadband China Strategy requires the deployment of 3G/LTE networks.
  - TDD can operate in unpaired spectrum, whereas FDD requires paired spectrum. Thus, TDD offers more flexibility in spectrum usage.

- Band Selection: UHF Band
  - Coexist with broadcast TV services to realize high efficiency of spectrum utilization.
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Technical Challenges

Challenge 1: Obtaining accurate cognitive information

Cognitive information is the basic of cognitive TD-LTE system operation

- Obtaining cognitive information simultaneously with transmitting information
- Obtaining cognitive information rapidly and accurately

Solution

- Re-design protocol and frame format to support acquiring cognitive information simultaneously with transmitting information
- Combine spectrum sensing and database to ensure both efficiency and accuracy
Frame Format Design and Protocol Design

Frame Format Design: UL-DL Guard Period and Uplink Time Slot are used to implement collaborative sensing. It enables real-time cognitive information transmission and breaks the limitation of conventional silence duration.

Protocol Design: The cognitive communication protocol is designed based on TD-LTE-Advanced protocol, by adding the cognitive functions.

In L3, we add new messages and RRC procedures for CRS, including the Sensing Management, RF-Band Management and Measurement Management.

To adapt to the changes in L3 and implement the cognitive functions, corresponding modifications are done in L1.
## Methods for obtaining cognitive knowledge

<table>
<thead>
<tr>
<th>Spectrum sensing</th>
<th>Database</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>- Suitable for dynamic changing environment</td>
<td>- Sensing time cost and hardware cost</td>
</tr>
<tr>
<td>- Fast local information update</td>
<td>- Miss detection, false alarm, location difficulty for hidden node</td>
</tr>
<tr>
<td>- Global information management</td>
<td>- Slow response to rapid changing radio environment</td>
</tr>
<tr>
<td>- Efficient information sharing</td>
<td>- Slow local information update</td>
</tr>
</tbody>
</table>

Both two methods of obtaining cognitive information have disadvantages!

Combine the two methods

- **Advantages**
  - Obtain global information via database, and update regional (local) information via spectrum sensing.
  - Overcome the hidden node problem, improve the accuracy of spectrum sensing, avoid interference, reduce the overhead.
**Three zones use case**

- Database stores accurate information, such as locations and borders of white zone, black zone and grey zone.
- The secondary users access database first and implement spectrum sensing only when necessary.

### Name Meaning Comment

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>White Zone</strong></td>
<td>Range Distance between PU and SU&gt;Y km</td>
<td>Secondary users beyond this range can deploy freely without spectrum sensing function.</td>
</tr>
<tr>
<td><strong>Black Zone</strong></td>
<td>Range Distance between PU and SU&lt;X km</td>
<td>Secondary users within this range can't work on the same spectrum as PUs absolutely, check the database.</td>
</tr>
<tr>
<td><strong>Grey Zone</strong></td>
<td>Range X km&lt;Distance between PU and SU&lt;Y km</td>
<td>Secondary users within this range should perform spectrum sensing before transmission.</td>
</tr>
</tbody>
</table>
**Technical Challenges**

**Challenge 2: Efficient spectrum management**

Spectrum management complexity increases with management scope.

Spectrum management should be applied:
- For both inter-cell and intra-cell
- Rapidly and efficiently

Two-level spectrum management mechanism:
- Global: inter-cell spectrum management, large time granularity
- Local: intra-cell spectrum management, small time granularity

**Solution**

Validated in the lab, the proposed mechanism has a 30% growth of spectrum utilization compared to fixed spectrum management.
Technical Challenges

Challenge 3: Adaptive to the changing environment

Adaptive reconfiguration is the key to deal with the changing environment

- Reconfiguration should be applied among heterogeneous networks
- Reconfiguration should improve QoS

Solution

- Service reconfiguration
- Protocol and parameter reconfiguration

Result

<table>
<thead>
<tr>
<th></th>
<th>Packet Loss Probability</th>
<th>Transmission latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Reconfiguration</td>
<td>5.36%</td>
<td>90.9965ms</td>
</tr>
<tr>
<td>After Reconfiguration</td>
<td>0.27%</td>
<td>27.9953ms</td>
</tr>
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❖ Testbed for Cognitive TD-LTE System
The platform is mainly composed of the Wireless Access side and Network side. It is designed to implement a cognitive network with centralized dynamic spectrum allocation to improve the spectrum efficiency and verify the heterogeneous network convergence.
Testbed for Cognitive TD-LTE System

Testbed characteristics

- **Spectrum Range of Testbed**
  - 700MHz-2.8GHz scalable spectrum range
  - Bandwidth: 1.25-20MHz
  - Frequency point switch time: <5ms

- **Support Multiple Standards**
  - 2G: GSM, CDMA
  - 3G: TD-SCDMA, WCDMA, CDMA2000
  - 3G+: LTE
  - IEEE: 802.11b/g/n, WiMAX

- **High Computing Ability**
  - 9 DSP cores with 1.2GHz high speed, 86.4G MIPs, 86.4G MACs
  - Support 2-4 antennas MIMO, support 100Mbps LTE standard
  - Satisfy various signal and protocol processing requirements of different wireless communication standards
  - Satisfy real time requirement of spectrum cognition in large scale

<table>
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<tr>
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<th>FCC standards</th>
<th>Platform Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing granularity</td>
<td>-114dBm</td>
<td>TV -120dBm Radar -113dBm</td>
</tr>
<tr>
<td>Sensing period</td>
<td>Off service : 30s On service : 60s</td>
<td>10ms</td>
</tr>
<tr>
<td>Sensing rate</td>
<td>N/A</td>
<td>TV 4ms Radar 3ms</td>
</tr>
<tr>
<td>Handover time</td>
<td>2s</td>
<td>50ms</td>
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Thank you for your attention!

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