**Problem Statement**

- Attackers can attack several network protocols at the same time, in a coordinated and smart way. Cross-layer attacks can:
  - cause larger damage to the network
  - be more difficult to detect
  - create new types of network failures
- Defense:
  - Single layer defense schemes no longer work
  - The defense has to go cross-layer.

**Cognitive Radio Networks (CRN)**

![Collaborative Spectrum Sensing](image)

**Single Layer Attacks in CRN**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Attacks in Cognitive Radio Networks</th>
<th>Damage to Primary User</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Layer</td>
<td>Primary User Emulation (PUE)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Reporting False Sensing Data (FSD-TA)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Reporting False Sensing Data (FSD-MD)</td>
<td>X</td>
</tr>
<tr>
<td>MAC Layer</td>
<td>Common Control Channel Denial of Service (CCDoS)</td>
<td>X</td>
</tr>
<tr>
<td>Network Layer</td>
<td>Routing towards Primary User (RPU)</td>
<td>X</td>
</tr>
<tr>
<td>Layers Above</td>
<td>Traditional Attacks</td>
<td>Depends</td>
</tr>
</tbody>
</table>

**Physical Layer Defense against RFSD Attack**

- Step 1: For node j, perform Neyman-Pearson test using reports from other (N-1) nodes to detect presence of primary user.
- Step 2: Based on test result of step 1, perform Neyman-Pearson test 2 to see if node j is lying or not.
- Step 3: Determine the physical layer trust value based on the binary observations of the node behavior (lying or not).

**MAC Layer Defense against SBW Attack**

![MAC layer back-off mechanism](image)

**Defense Scheme**

- Deduce the distribution of back-off window size
- Observe the actual back-off window size
- Evaluate the difference of the two distributions

**Cross Layer Attack**

- Conduct RFSD attack with probability \( P_1 \) in PHY layer
- Conduct SBW attack with probability \( P_2 \) in MAC layer
- There exists an optimal \( P_1 \) and \( P_2 \) so that single layer defense can not detect the malicious user

**Cross Layer Defense**

- Deduce the distribution of back-off window size
- Observe the actual back-off window size
- Evaluate the difference of the two distributions

**Simulation Results**

![Simulation Results](image)

**Impact**

- Demonstrated the damage of cross-layer attacks;
- Effectively secured cognitive radio networks;
- Proposed a generic cross layer defense framework that can be applied to many other networks.