PARADIS
PAssive
RAdiometric
Device
Identification
System

:Identifying Transmitters via Radiometric Signatures

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Radiometric Identification

- RF Fingerprinting
  - Radiometric Identification
  - Location Identification
    - Modulation Domain (our work!)
    - Waveform Domain
Waveform Impairments in Analog Frontend

- **Transmitter**
  - Hardware imperfection
  - Design architecture

- **Receiver**
  - Allows certain level of difference for interoperability
Error Signal Vector

- Measurement Tool
  - Vector Signal Analyzer: Agilent VSA 89641S
PARADIS (PAssive RAdiometric Device Identification System)

Training phase

Collect RF Fingerprint

Build Error Metric

On-line (Identification) phase

Measure the target Signal (Bin size = m)

Identify the Device
Training Phase

- Collect fingerprint of each transmitter (20 frames each)
- Build a Reference Table based on Error Metrics
  - User device = {A,B,C,D}
  - Collect frames per device \{a_1,a_2,a_3,\ldots,a_n\}
  - Measure sample vector \( V = (v_1,v_2,v_3,v_4,v_5) \)

<table>
<thead>
<tr>
<th>Error type</th>
<th>unit</th>
<th>reference</th>
<th>range</th>
<th>definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>frequency</td>
<td>Hz</td>
<td>2142 MHz</td>
<td>±60.3</td>
<td>±25 ppm ( f_c )</td>
</tr>
<tr>
<td>phase</td>
<td>°</td>
<td>ideal symb</td>
<td>±10</td>
<td>asin(( E_{max} ))</td>
</tr>
<tr>
<td>magnitude</td>
<td>n/a</td>
<td>ideal symb</td>
<td>±0.17</td>
<td>±( E_{max} )</td>
</tr>
<tr>
<td>EVM</td>
<td>n/a</td>
<td>ideal symb</td>
<td>[0,.35]</td>
<td>upto 2( E_{max} )</td>
</tr>
<tr>
<td>I/Q offset</td>
<td>n/a</td>
<td>ideal origin</td>
<td>[0,0.17]</td>
<td>upto ( E_{max} )</td>
</tr>
<tr>
<td>SYNC</td>
<td>%</td>
<td>max corr.</td>
<td>[0,1]</td>
<td>correlation</td>
</tr>
</tbody>
</table>

\( f_c \) – channel frequency \( E_{max} \) – max I/Q error
Classification Algorithms

• PARADIS-kNN (k-Nearest-Neighbor)
  – In training, discard ½ samples (outliers) of user A
    • Average value of the rest ½ is model $M_a$ of user A
  – For given sample $u_k$, calculate similarity with models for all the users
    • Find least value from $\{|M_a-u_k|, |M_b-u_k|, |M_c-u_k|, |M_d-u_k|\}$

• PARADIS-SVM (Supported Vector Machines)
  – Use of LIBSVM
    • Classification algorithm that builds N-1 dimensional hyper plane in N dimensional space
ORBIT
Performance

<table>
<thead>
<tr>
<th>Approach</th>
<th>NIC population size</th>
<th>Bin size</th>
<th>Training fraction</th>
<th>Reported error rate$^1$</th>
<th>Equivalent performance of PARADIS-kNN</th>
<th>PARADIS-SVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Franklin et. al. [13]$^2$</td>
<td>17</td>
<td>8</td>
<td>5%</td>
<td>15%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Hall et. al. [18]$^3$</td>
<td>30</td>
<td>10</td>
<td>33%</td>
<td>8%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>PARADIS</td>
<td>138</td>
<td>4</td>
<td>20%</td>
<td>-</td>
<td>3%</td>
<td>0.34%</td>
</tr>
</tbody>
</table>

- Franklin:
  - Use 802.11 device driver fingerprint
  - Detect implementation dependent probing algorithm

- Hall:
  - Detect signal transient time in the waveform domain

- PARADIS:
  - Error vector in the Modulation domain
Performance I

- False Reject Rate (FRR) – per NIC
  - System denies authentic users
Performance II

- False Accept Rate (FAR) – per NIC
  - System authenticate wrong user (imposter)
  - Worst case similarity: Select the most probable imposter
Calibration

- SVM algorithm need calibration time
  - But frame by frame identification is possible.
Conclusions

• PARADIS
  – Identifying devices using modulation domain fingerprint is possible with a great precision
  – Accuracy > 99%
  – Error < 1%

• Key features
  – Consistency
  – Unforgeable
  – Unescapable

• Implications
  – Could be used in intrusion detention systems
  – Possible privacy compromise