Cooperative Cell Outage Detection in Self-Organizing Femtocell Networks

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Trends in Next-generation Cellular Networks

• Autonomic management: self-configuration, self-optimization, self-healing
  – 3GPP TS 32.522 Rel. 9
  – 3GPP TS 36.902 Rel. 10

• Smaller femtocell within homes & enterprises
  – 3GPP TR 25.820
Cell Outage Detection is Important

- Cell outage detection is the 1\textsuperscript{st} step towards self-healing.
  - Outage cell: inoperable / cannot provide service
  - Hardware/software failures, misconfigurations. [3GPP TS 36.902]
  - Autonomously detect cells in an \textit{outage} state

- Cell outage
  $\rightarrow$ decreased capacity & coverage gap
  $\rightarrow$ high user churn rate & operational costs
Cell Outage Detection is Non-trivial

- Current detection: considerable manual analysis & unplanned site visits.
  - Operations Support System (OSS) can only detect some outage cases
    - Performance counters and/or alarms.
  - Others may take hours/days
    - long term performance analyses and/or subscriber complaints
Femtocell Brings Extra Challenges

• Macrocell detection architecture not applicable
  – Dense Deployment
    • Centralized management involves high communication overhead
  – Sparse User Statistics
    • Typically 1-4 active users per femtocell. Not enough Key Performance Indicators

• WLAN detection architecture not applicable
  – Two-tier architecture
    • Vertical Handover
    • Disconnection based trigger not applicable
Our Target

An Efficient Outage Detection Architecture for Femtocell Networks
Outline

• Problem Definition
• Design Rationale
• The Proposed Architecture
• Results
• Conclusions & Future Work
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Problem Definition

• Network Model
  – A set of femtocells overlaid on a macrocell
  – Users periodically report Reference Signal Received Power (RSRP) statistics

• Problem
  – Timely detect an outage femtocell in the network
Outline

• Problem Definition
• **Design Rationale**
• The Proposed Architecture
• Results
• Conclusions & Future Work
Design Rationale

• Requirements

Communication overhead minimized
✓ A distributed trigger mechanism
✓ Minimizing detection time
Design Rationale

• Requirements

Communication overhead minimized
  ✓ A distributed trigger mechanism
  ✓ Minimizing detection time

Vertical HO considered
  ✓ A trigger mechanism to filter out this case
# Design Rationale

## Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Solution</th>
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<td>✓ Minimizing detection time</td>
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<tr>
<td>Vertical HO considered</td>
<td>✓ A trigger mechanism to filter out this case</td>
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<tr>
<td>Few active users</td>
<td>✓ A robust detection rule</td>
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Observation

• [Chen, 2011] shows that users in close proximity have similar signal statistics.

• Observation: **Spatio-temporal correlations** in RSRP statistics can be leveraged.
An illustration

- Normal case

- Outage case
• **Vertical HO case**

Disconnection based trigger can’t differentiate these two cases.
An illustration

- Normal case
  - Users in close proximity have similar signal statistics.
  - Locations of U2 are probably close.

- Outage case
An illustration

- **Normal case**
  
  Locations of U2 are probably quite different.

- **Vertical HO case**

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<tr>
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<th>FAP3</th>
<th>FAP4</th>
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<td>1(+)</td>
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Design Rationale

• Observation: **Spatio-temporal correlations** in RSRP statistics can be leveraged.
  – Tackle vertical HO issue
  – A femtocell can check the states of its neighbor femtocells
  – Multiple femtocells can cooperatively process RSRP statistics
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Overview

• Before the trigger stage,
  – each FAP stores a copy of benchmark data beforehand,
    • which is collected when all FAPs are normal.

• In the trigger stage,
  – the FAP predicts the expected normal RSRP statistics based on the benchmark data via collaborative filtering.
  – Compare expected normal RSRP with current RSRP

• In the detection stage,
  – all the FAPs within the cooperation range report the statistics collected in trigger stage to the MBS periodically
  – until the MBS collects enough information for making a final decision.
The Proposed Architecture

User

Reports RSRP statistics to the associated FAP

FAP

Predict normal RSRP statistics via collaborative filtering

Are current statistics normal?

YES

trigger message

NO

Benchmark Data

The Trigger Stage

FAP reports current RSRP statistics to MBS

Process current RSRP statistics via data fusion

Update decision statistic \( \Lambda \)

\( \eta_0 < \Lambda < \eta_1 \)

YES

NO

Final decision

The Detection Stage
The Proposed Architecture

• Trigger stage
  – Normal RSRP statistics prediction: collaborative filtering

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<tr>
<td>U5</td>
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Benchmark data

– Trigger decision
  • Compare predicted RSRP with observed RSRP
    – Similar → keep monitoring
    – Different → trigger detection stage
The Proposed Architecture

• Detection stage
  – Based on sequential hypothesis model

\[
\Lambda_T \triangleq \ln \frac{p(\theta_1, \ldots, \theta_T | \mathcal{H}_1)}{p(\theta_1, \ldots, \theta_T | \mathcal{H}_0)},
\]

\[
\begin{align*}
\Lambda_T \geq \eta_1 & \quad \Rightarrow \text{accept } \mathcal{H}_1 \\
\Lambda_T \leq \eta_0 & \quad \Rightarrow \text{accept } \mathcal{H}_0 \\
\eta_0 < \Lambda_T < \eta_1 & \quad \Rightarrow \text{take another detection round,}
\end{align*}
\]
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Analytical Results

- Average detection delay analysis

\[
E[T|\mathcal{H}_0] = \frac{\sigma_0^2 \beta \ln \frac{1-\alpha}{\beta} + \sigma_0^2 (1 - \beta) \ln \frac{\alpha}{1-\beta}}{(N_o - \frac{\mu_1 + \mu_0}{2}) (\mu_1 - \mu_0) \rho \pi R^2}
\]

*Proposition 1:* The average outage detection delay is inversely proportional to the user density and the cooperation area (i.e. \(\rho \pi R^2\)), but is independent of the FAP’s transmission power.
Numerical Results

• Overall Performance
  – The proposed framework: COD
  – Compare with maximum likelihood based approach: MAJ

• Impacts of Parameters on detection delay
Overall Performance

- COD outperforms MAJ in detection accuracy by more than 20%
Overall Performance

- The difference in the detection delays of COD without trigger stage and COD approaches zero when FAP transmission power increases.
Impacts of Parameters on Detection Delay

- Numerical results match the analytical results.
Conclusions & Future Work

• Conclusion
  – We propose correlation based outage detection architecture in consideration of the unique challenges in femtocells
    • Can be used as a general framework for outage detection
  – We identify the impacts of the cooperation range and the user density on detection performance

• Future work
  – Cope with multiple concurrent outages
Thanks!
Any Questions?

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