Small cell networks, self-healing and context-awareness

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1. Introduction
2. Management architecture for context-aware SON
3. Context-aware self-healing framework
4. Contextualized network indicators
5. Distributed approach for sleeping cell analysis
6. Conclusions
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Small cell networks, self-healing and context-awareness
Motivation

Small cell networks, self-healing and context-awareness
Motivation – Growing cellular demand

- Growing demand for mobile communication
  - Increased number of users and data traffic.

- Flat Rate
  - Reduced returns.

- Mechanisms to meet demand
  - New technologies.
  - Higher BW in higher frequency bands.
  - More frequency reuse.

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Growing cellular demand

- UL + DL mobile data traffic [Exabytes/month]

Data traffic grew 70% between Q1 2016 and Q1 2017

Source: Ericsson traffic measurements (Q1 2017)

Traffic does not include DVB-H, Wi-Fi, or Mobile WiMAX. VoIP is included in data traffic.

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Motivation – Small cells

- The classic macro cell-tower
  - Visible, large.
Motivation – Small cells

- The classic macro cell-tower
  - Tri-sectorial.
  - Coverage of Kms - hundreds of meters. Ptx=40 W (typ.).
  - Expensive, high investment, costly maintenance.
  - Coverage issues at indoors, urban valleys → worst with increase. freq.

Source: Ana Gómez Andrades

RSRP (Reference Signal Receive Power) [dBm]

Source: http://www.forsk.com/propagation-modelling

Source: https://eledia.science.unitn.it/sito/index.php/ricerca/8-ricerca/229-3g-and-4g-radio-network-planning

Source: http://www.forsk.com/propagation-modelling
Discussion:

- Why increasing frequency?
- What is the issue in higher freqs.?
Motivation – Small cells

- **Discussion:**
  - Why increasing frequency?
  - What is the issue in higher freqs.?

- The spectrum is a **limited resource**.
- **Higher frequencies** allow wider bandwidth → increase data rates.
  - Current LTE < 6 GHz.
  - 5G > 6 GHz (60 GHz band and even higher)
- However they imply **higher radio losses** (attenuation) and more complex electronics.
Motivation – Small cells

- Small cells - low powered cellular base stations
  - Dense: coverage 10s of meters.
  - Specific spots coverage.
  - Increase frequency reuse.

http://www.tektelic.com/solutions/small-cell-solutions/
Motivation – Small cells

- A much more pervasive and concealed infrastructure.
- Faster/easier installation.
- Cheaper individual systems and maintenance.

https://www.mobileeurope.co.uk/trends/small-cells?limit=50&start=100

http://blog.spidercloud.com/author/admin/page/4/
Motivation – Small cells

- **Microcell**: outdoor, <1 km, 5W (typ.) – controlled power for a certain area.

- **Picocell**: indoor, <200 m, typ. 2W (typ.).

- **Femtocells**: indoor, few 10s of meters, <200mW, home scenarios (typ.).
**Motivation – Small cells**

- **Other categorizations**
  - **Femto-backhaul “femtocell technology”:**
    - Non dedicated connection to the core by broadband (e.g. DSL) → Home NB → HeNB.

- **Metrocell:**
  - Small cell installed in lamp post or other urban elements.

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Links:
- [Femto-backhaul “femtocell technology”](http://smallcells.3g4g.co.uk/2013/05/china-mobile-and-ericsson-deploy-gsm.html)
- [Metrocell](http://goughlui.com/2015/07/04/salvage-hts541680j9sa00-80gb-hdd-duracell-aaa-optus-cable-card-alcatel-lucent-home-cell/)
Motivation – Small cells

- Not everyone follows the nomenclature!

https://www.imore.com/att-microcell-boost-iphone-reception-5-markets

Joseph Thornton / Flickr
Motivation – Small cells

- **Other non-classical provisions**
  - Relays – retransmit.
  - Remote radio heads (RRH).

- **The trend: centralized the radio processing.**
  - Shared base station server.
  - Synergies between stations, faster coordination.

- **Not so long ago → decentralized the processing...**
Motivation – Small cells

- Different deployments and technologies → heterogenous networks (HetNets)
- Many times co-located with macro and supported by its backhaul.
Motivation – Small cells

- Growing deployment.
  - 14 millions, 1.7 shipment annually

The small cell industry has ‘crossed the chasm’ to a phase of rapid market growth
**Motivation – Small cells**

- **Growing deployment.**
  - 14 millions, 1.7 shipment annually

> The small cell industry has ‘crossed the chasm’ to a phase of rapid market growth

- **14 million SCs shipped**
  - Shipment growth 2016: 270% Enterprise, 150% Urban

- **$1 billion revenue in 2015**

- **$6 billion revenue 2020**

- **41% CAGR in revenue thru 2020**
  - 61% enterprise
  - 25% urban

Download our market status report at scf.io for more details

Source: Mobile Experts Q116

© Small Cell Forum Ltd 2016
Motivation – Small cells

- Indoor scenarios
  - Corporate buildings, malls, airports.
  - 75% of traffic.
  - Coverage/capacity problems.

http://www.tektelic.com/solutions/small-cell-solutions/
Motivation – Small cells

- Large numbers of cells and deployment types.
- Simultaneous technologies (GSM, UMTS, LTE, 5G)
- Operation, administration and management (OAM) of many different elements
  - tasks associated to the planning, configuration, optimization and failure management of the network components.

→ Increasing complexity.
Small cell networks, self-healing and context-awareness
Motivation - SON

Self-Organizing Networks (SON)

- NGMN & 3GPP.
- High complexity OAM → Automatization.
- Increasing efficiency and reducing costs.

Main functionalities:

- **Self-configuration**: elements initial deployment.
- **Self-optimization**: re-configuring parameters.
- **Self-healing**: automatic failure management.
Motivation - SON

- SON systems are implemented as part of the OAM architecture: NE, DM, NM and closer to the control plane.
- 3GPP introduced the general SON concept and functions in the LTE standard.
  - Qualitative manner and use cases, general scheme and requisites.
- The specific algorithms are open for research and implementation.
- Multiple research projects
  - Gandalf, Freedom, BeFemto...
Motivation - SON

Three main categories

- **Self-configuration**: elements initial deployment.
  - Automatic assignment of Phy. Cell ID and Scrambling codes...

- **Self-optimization**: re-configuring parameters.
  - Load balancing, handover optimization, energy saving...

- **Self-healing**:
  - failure detection, diagnosis, compensation and recovery.
Self-optimization – General diagram

- Reconfigure the network elements parameters to improve the network performance.

![Diagram of self-optimization system](image)

- Metrics (e.g. dropped calls)
- Configuration parameters (Tx power)

Cellular network
Self-healing – Scheme

- Cellular network
- Drive test
- Cell-level metrics
- UE-level information
- Detection
- Problems
- Diagnosis
- Causes / faults
- Compensation / recovery
- Actions
Self-healing – Scheme

- **Problems**: defined as situations of degraded service. For example, an increase in the percentage of dropped calls or access failures, reductions in the available throughput, the signal quality, etc.

- **Cause/fault** of a problem: refers to the specific software or hardware malfunction that led to the service degradation. Typical causes include base station (BS) disconnection, interference, parameters misconfiguration, failures in the BS components, etc.
Self-healing – Scheme

- **Problems:**
  - defined as situations of degraded service. For example, an increase in the percentage of dropped calls or access failures, reductions in the available throughput, the signal quality, etc.

- **Cause/fault of a problem:**
  - refers to the specific software or hardware malfunction that led to the service degradation. Typical causes include base station (BS) disconnection, interference, parameters misconfiguration, failures in the BS components, etc.

- **Detection** identifies the presence of problems, **diagnosis** defines their causes/faults.
- Problems are typically defined at cell level.
Self-healing – Scheme

Cellular network → Drive test → Cell-level metrics → UE-level information → Self-healing

Detection → Problems → Diagnosis → Causes / faults → Compensation / recovery → Actions

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Cell-level metrics

- Base of classical approaches: status monitoring, alarms, counters, KPIs.
  - Drop call rate, call blocking rate...
- One value each observation period (e.g. 1 hour) → statistics.

Detection / diagnosis
Self-healing – Sources: Drive test

- Using specific terminals for the analysis of the network coverage.
- GNSS (GPS) positioning.
- Moving by car, walking, drone...
- Dedicated companies, costly measurements.

https://dir.indiamart.com/impcat/drive-test-services.html
Minimization of Drive Test (MDT)

incorporated to the 3GPP standard in recent years, enriches previous trace mechanisms by adding localization information to the UE reports.

Here, UE positions are typically estimated by means of cellular techniques, e.g. cell id, timing advance (TA), time of arrival (ToA), time difference of arrival (TDoA)...

Self-healing – Sources: MDT
Self-healing – Sources

- **UE-level information**
  - UE traces, drive tests, MDT...
  - Complex processing → coverage maps...
  - Difficult to adapt to existing automatic methods and indoor.

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**Diagram:**
- BS
- GNSS
- Cellular-based loc.
- Expert analysis

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- Not identified
- Coverage hole
- Cell edge
- Lack of dominants
- Mobility problems
- Interference

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Motivation - Features and challenges

- **Small cell networks**
  - Coverage of 10s of meters.
  - Period with few or no users.
  - Very fast performances changes.
  - Overlapping (intra and inter).

- **Challenges in the use of cell-metrics**
  - *Detection*: threshold, time-series analysis, fuzzy rules, correlation...
  - *Diagnosis*: classifiers, supervised and unsupervised learning...
  - Dependent on the statistical difference between “cases”.
  - Limited with cell-metrics.

→ Other information variables?
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Motivation - Context variables

- **Context**
  - Those variables not directly associated with the telecommunication service itself, but that can impact it.
  - UEs, network equipment and external elements.
  - Smartphone and tablets → more computational capacity, plenty of sensors.
  - Social data, personalized online services, free databases...
Motivation – Indoor positioning

Indoor localization
- Outside GNSS coverage, macro-cellular...
- Required for “killer apps” and personalized services.
- Techs: WiFi, small-cellular, RFID, UWB...
- Expected to be fully available in 5G.
Motivation – Example

- **Classical profiles**
  - Non-contextualized indicators. No clear statistical deviation between cases.

- **Statistical relevance of the data based on positioning information.**

- **Contextualized information:**
  - Only measurements of interest are considered. Clear distinction between normal and non faulty cases and between different faults is achieved.
Integr. SON & Positioning (I) - Synergies

Self-Organizing Networks (SON) for Small Cells

- Deployment configuration for communications (and localization).
- Information about failures, change of parameters, etc.
- Used for the fine adjustment of the configuration parameters → SO
- Asset for the detection/diagnosis compensation and recovery of network failures → SH

Localization

- Requirement for cellular-based localization (e.g. radio measurements analysis, ToA...).
- Asset to keep the quality of localization services (e.g. recalculation depending on cell failures).
- Information on user equipment positions.
Integration SON & Positioning (II) - Issues

- A useful integration
  - Small cells + SON allow localization services.
    - Using cellular infrastructure
    - Localization performance against failures
  - Localization is a useful source of info for SON, allowing fine tuning mechanisms
Objectives

- Integration of context (and especially localization) and SON for small cell networks.
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Architecture - Objectives

- **SON and context sources have very different characteristic:**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Context sources</th>
<th>OAM/SON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main elements</td>
<td>UEs, context services</td>
<td>OAM architecture, BSs</td>
</tr>
<tr>
<td>Time span</td>
<td>s/ms</td>
<td>Classic: daily, weekly; foreseeable: hours, mins</td>
</tr>
<tr>
<td>Spatial scope</td>
<td>Local scenario/spot</td>
<td>Operator's network, subnetwork</td>
</tr>
<tr>
<td>Responsible</td>
<td>Third parties, end-users</td>
<td>Operator</td>
</tr>
</tbody>
</table>

- **An architecture to bring the SON to the context level:**
  - Integration with previous OAM mechanisms and architecture.
  - Communications versatility.
  - Reduced signaling.
  - Management speed.

- **Concept**
  - A local-SON entity in charge of a particular cellular deployment → focus on combination with local indoor localization systems.
Architecture - Functional model

- 3GPP OAM plane
  - Interfaces and element functionalities.

<table>
<thead>
<tr>
<th>Entity</th>
<th>Task</th>
<th>Parameter abstraction</th>
<th>Time span</th>
</tr>
</thead>
<tbody>
<tr>
<td>NM</td>
<td>Planning</td>
<td>Vendor independent</td>
<td>weeks / month</td>
</tr>
<tr>
<td>EM/DM</td>
<td>Network operation</td>
<td>Vendor independent / specific</td>
<td>hours / days</td>
</tr>
<tr>
<td>NE</td>
<td>Element config.</td>
<td>All parameters</td>
<td>s / min</td>
</tr>
</tbody>
</table>
3GPP OAM plane

- Interfaces and element functionalities.
SON Architecture - Implementation

- Femtocell (non-dedicated backhaul) oriented scheme.
- Available integration in the LTE/LTE-A standard plane or over-the-top.
- Direct LAN connection and without crossing the operators’ core.
- Reduced signaling.
Evaluation - PTS’

- Showcase of the capacities of integration between SON and context and the proposed architecture.
- Load Balancing (LB)
  - Fair distribution in the use of resources between the cells of the area.
Evaluation - PTS’

**Baseline - PTS’ (Power Traffic Sharing):**
- Load balancing by changing the transmitted power.

**Inputs**
- Transmitted power
  \[
  \Delta Ptx(cell_i, t) = Ptx_{max}(cell_i) - Ptx(cell_i, t),
  \]
- Load difference
  \[
  load_{diff}(cell_i, t) = load(cell_i, t) - \frac{1}{|\text{Adj}(cell_i)|} \sum_{\forall \text{cell}_j \in \text{Adj}(cell_i)} load(cell_j, t),
  \]

**Outputs**
\[
Ptx(cell_i, t + 1) = Ptx(cell_i, t) + \delta Ptx(cell_i, t + 1),
\]
Discussion:

- A method to define a controller based on linguistic rules applied over numerical inputs/outputs?
**Evaluation - Fuzzy logic controller**

- **Fuzzy logic controller**
  - Linguistic rules.
  - Reduced speed for each step due to the risk of oscillation and overshooting.
  - The defined controller: Takagi-Sugeno-Kang – linear or constant membership functions.

Fuzzy logic controller

- Reduced speed for each step due to the risk of oscillation.
- The defined controller: Takagi-Sugeno-Kang – linear or constant membership functions
Evaluation - Fuzzy logic controller

- **Input membership functions**
  - Converts load and power values to fuzzy values.

![Diagram showing fuzzy membership functions for load difference and power change](image_url)
Fuzzy logic controller

- Reduced speed for each step due to the risk of oscillation.
- The defined controller: Takagi-Sugeno-Kang – linear or constant membership functions
## Evaluation - Fuzzy logic controller

### Fuzzy rule base

- **Linguistic rules.**

<table>
<thead>
<tr>
<th>load((cell_i, t)_{diff})</th>
<th>Operator</th>
<th>Δ(Ptx(cell_i, t))</th>
<th>δ(Ptx(cell_i, t + 1))</th>
</tr>
</thead>
<tbody>
<tr>
<td>VN</td>
<td>AND</td>
<td>VN</td>
<td>VP</td>
</tr>
<tr>
<td>VN</td>
<td>AND</td>
<td>N</td>
<td>VP</td>
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<td>VN</td>
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<tr>
<td>VP</td>
<td>AND</td>
<td>-</td>
<td>VN</td>
</tr>
</tbody>
</table>
**Evaluation - Fuzzy logic controller**

- **Fuzzy logic controller**
  - Reduced speed for each step due to the risk of oscillation.
  - The defined controller: Takagi-Sugeno-Kang – linear or constant membership functions
Evaluation - Fuzzy logic controller

- Output membership functions
  - Converts fuzzy values of transmitted power change to numerical values.
  - Reduced speed for each step due to the risk of oscillation.

\[ \delta P_{tx}(cell_i, t+1) \] [dB]
Evaluation - LPTS’

- Reduced variation in each algorithm epoch due to the risk of oscillation and overshooting.
- **LPTS’ – location-aware PTS’**
  - User positions as a new input.
  - What if we could increase the speed of the process knowing the users positions?
  - Accelerator parameter → simple initial step: concentration in the center → increase the output.
Evaluation - Scheme

- Implementation in the OCAS architecture.

**OCAS**

SAU (SON Algorithmic Unit)

Load balance optimization

LPTS'

\( \alpha (\text{cell}, t+1) \)

Users-positions distribution analyzer

\( \delta Ptx(\text{cell}, t+1) \)

FLC

PTS'

\( \text{load}_{\text{d}+\text{f}} \)

\( \Delta Ptx \)

Context Collector Unit

User positions\((t)\)

Context Services

CS-OCAS /PCU Itf

**Proposed additions**

Standard 3GPP OAM Architecture

EM NE SON

(Small cell)

NE-OCAS/ACU Itf

NE-OCAS/MEU Itf

UE-OCAS/PCU Itf

UE
Evaluation - Analysis

- LTE system-level simulator.
- User distributions variations.
- Mechanisms:
  - Without SON, PTS', LPTS'
- Algorithm epoch time – reduced by having local architecture:
  - 1 hour, 15 minutes
- Main KPI
  - **UUR** (Unsatisfied User Ratio)
    \[ UUR = CBR + OR(1 - CBR), \]
  - **CBR** (Call Blocking Ratio): number of blocked calls / calls attempting to access the network.
  - **OR** (Outage ratio): possibility for an existing connection to stay in standby before it is finished.

**Main KPI**

- **UUR** (Unsatisfied User Ratio)
  \[ UUR = CBR + OR(1 - CBR), \]
- **CBR** (Call Blocking Ratio): number of blocked calls / calls attempting to access the network.
- **OR** (Outage ratio): possibility for an existing connection to stay in standby before it is finished.
Evaluation - Results

- Degradation in the performance.
- Period 1h → 15min, PTS’ → LPTS’. Faster convergence, better values.

Outlook:
- Increasing periodicity is required for SON in small cells.
- The LPTS’ concept is based on more refined analysis of the cellular network of the user distributions: associated papers and thesis in self-optimization.

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Motivation and framework elements

- **Goal:**
  - Providing a reference logic framework for the development of context-aware self-healing mechanisms.
  - UE focus.

- **Main elements**

  ![Diagram of self-healing framework]

  - **Indicators acquisition**
  - **Context aggregator**
  - **Inference engine**
  - **Record update**
  - **Problems**
  - **Causes / faults**

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Framework - UE-profiling based model
PoC: Cell outage detection

- Mapped in the logical framework
- Statistical comparison between expected given context and current
  - Indicator contextualized profiles  \( \hat{\rho}_{\text{ctx}}(m, \text{ctx}(u)) \)
  - Terminal current profiles  \( \hat{\rho}_{\text{term}}(m, u) \)
  - Divergence
- Multiple options
  - Profiles: Means, histogram, Gaussian, beta...
  - Divergence: f-divergence (KL distance, Hellinger), pdfs cross-correlation...
- Inference
  - JWDev: Joint weighted deviation mean
  - Rules: thresholds.

Indicator contextualized profiles  \( \hat{\rho}_{\text{ctx}}(m, \text{ctx}(u)) \)
Terminal current profiles  \( \hat{\rho}_{\text{term}}(m, u) \)
Divergence
Multiple options
Profiles: Means, histogram, Gaussian, beta...
Divergence: f-divergence (KL distance, Hellinger), pdfs cross-correlation...
Inference
JWDev: Joint weighted deviation mean
Rules: thresholds.
Test trial – Set-up

- **Real femtocell office environment**
  - 55x25 meters.
  - 4 UMTS femtocells - Alcatel-Lucent 9365 Base Station Router Femto.
  - Multiple terminals.
  - App Android for RSCP values reporting.

![Diagram of femtocell setup]

- **Typical office environment**
  - External Wall: Glass + Brick
  - Internal Wall: Glass
  - Internal Wall: Wood
  - Internal Wall: Brick
  - Internal Wall: Elevator
  - Doors: Wood
  - Doors: Glass
  - Doors: Metal
  - Doors: Metal + Wood
  - Doors: Elevator

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Example case
- 2 terminals.
- 3 meters area.
- 90s buffer
- Lack of reception from one cell does not indicate anything without location-info.
- “Shadow cell” makes even more difficult the detection of issues.
- JWDev provides proper information for detection.

Test trial - Real implementation

- A little demo.
Test trial - Real implementation

- A little demo.
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Motivation – Classic approaches

- **UE profiling method**
  - Multiple buffers, individual context history.
  - Imply changes of approach in comparison to classical KPI-based mechanism.

- **Cell-level metrics**
  - DenseNets: Low detail, low impact.
  - Easy to process by common mechanisms: threshold, classifiers. Also, easy to check by human experts.

**Goal:** integrate UE context as part of metric-like inputs for detection and diagnosis → **Contextualized indicators.**
Contextualized indicators - Formulation

- $\gamma(ue, \tau)$, the context of an $ue$ for a certain instant $\tau$ can be described as a multidimensional vector.

$$\gamma(ue, \tau) \sim \{x(ue, \tau), y(ue, \tau), z(ue, \tau), sc(ue, \tau), \ldots\} ,$$

- This is integrated in the contextualized indicator

$$f_{ctx}[t] = \hat{\theta}(\{m'(ue, \tau), \gamma(ue, \tau) | \forall ue \in U E_{SC}, \forall \tau \in t\}) ,$$

- $\hat{\theta}$ - any statistic, estimator or algorithm.
Objectives: change relevance, select groups, specific filtering...for any statistic → sample weights

- Social polling: vary the relevance of each sample.
- Empirical pdf → histogram → distr. fitting → statistics.

\[ epdf_{ctx}(m) = \frac{1}{E_w} \sum_{M'} \delta(m - m'(ue, \tau)) \cdot w(\gamma(ue, \tau)), \]

Also direct weighted statistics calculation.
Contextualized indicators - Weight masks

- **Total weight** → multiple weights functions (masks)
  - Different set of weight functions (for different set of context variable) can be applied to the same set of terminals

\[
\mathbf{w}_T(\gamma(ue, \tau)) = \phi\left( \{ w_{loc}(\gamma_{xyz}(ue, \tau)), w_{sc}(\gamma_{sc}(ue, \tau)) \ldots \} \right),
\]

- **Simplified approach** → binary (logical) weights
  - One of the possible options.

\[
w(\gamma(ue, \tau)) = \begin{cases} 
1 & \text{if } \gamma(ue, \tau) \text{ met } w \text{ defined conditions} \\
0 & \text{otherwise}
\end{cases}
\]

- Simplifies the approach and the statistic calculation (no need for epdf).
- Total weight is calculated by AND-OR of the different masks.
  - e.g. terminals using video AND dist. to cell X < 5m AND served by cell Y AND ...
**Discussion:**

- Classifier to obtain the probability of a certain network fault/case given a certain set of evidence (indicators)?
Once indicators are generated → input for any diagnosis mechanism

Naive Bayes classifier:

\[
\hat{p}(C = c_s | F = f[t]) = \frac{\hat{p}(C = c_s) \prod_{F \in F} \hat{p}(F = f[t]| c_s)}{\hat{p}(F = f[t])}
\]

- Set of input indicators \( F = \{F_{cls1}, F_{cls2}, \ldots, F_{ctx1}, F_{ctx2}, \ldots\} \)
- Evidence \( f[t] = \{f_{cls1}[t] \ldots f_{ctx1}[t], \ldots\} \)
- \( F_{ctx} = f_{ctx}[t] \) value in the observation period ‘t’ for a particular contextualized indicator generated by a set of weight mask ‘ctx’.
- Conditional probabilities \( \hat{p}(F_{ctx} = f_{ctx}[t] | c_s) \) given network state (normal or one specific fault cause).

Phases
- Training: conditional probabilities and prior probabilities calculation.
- Online: current values of the inputs of the classifier → posterior probabilities → MAP rule.
Context-aware diag. - Concept

- Combine network measurements and UE context.
- Different weights $\rightarrow$ different indicators.
- Applicability $\rightarrow$ select the weights depending on the failure to diagnose.

Contextualized indicators

- Combine network measurements and UE context.
- Different weights $\rightarrow$ different indicators.
- Applicability $\rightarrow$ select the weights depending on the failure to diagnose.
### Framework implementation
- The need for buffers and historical data for individual UEs is avoided.
- Statistics estimator for the generation of the indicators.
- Naïve Bayes classifier is used for the diagnosis of the network status/fault.

### Data scarcity
- Binary weighting process can lead to limited number of samples in one observation period → not enough for the indicator.
- Approaches
  - **Discard indicator**: reduce the number of inputs to the classifier.
  - **Fallback**: use the classic indicator.
  - **No diagnosis**: better to not provide results.
Evaluation – Set-up

- LTE system level simulator.
- Large airport area.
- 12 small cells, closest macro 376m.
- UEs distribution variation.
- UE 1s reporting period, 1min observation period.
- 144 periods per failure and cell, 50 periods training set.
Evaluation – Radio based failure cases

- Set of common radio problems
  - Location-based / serving cell masks most impacted users.

- Binary location mask based on available information
  - Coverage: Voronoi + radius + building contour.

- Indicator selection
  - Interference \(\rightarrow\) CQI-based (SINR).

<table>
<thead>
<tr>
<th>Failure</th>
<th>Classic cell indicator</th>
<th>Contextualized indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small cell interference</td>
<td>Interfered cell</td>
<td>Interfered cell EDGE and served by it</td>
</tr>
<tr>
<td>Macro interference</td>
<td>Small cell close to macro and building perimeter</td>
<td>Small cell close to macro and building perimeter EDGE and served by it</td>
</tr>
<tr>
<td>Power degradation</td>
<td>Served by adjacent</td>
<td>Degraded cell CENTER</td>
</tr>
</tbody>
</table>
Evaluation – Indicators (time distribution)

- Comparison between classic and contextualized indicators → Cell 11 case.

![Graph comparing classical and contextualized indicators over time with different events including Normal, SC interf., Macro interf., and Power degr. for both Classical and Contextualized indicators with legend.]
## Evaluation – Indicators

### Comparison between classic and contextualized indicators → Cell 11.

<table>
<thead>
<tr>
<th>Main identifiable fault</th>
<th>Classic Indicators</th>
<th>Contextualized Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small cell interf.</td>
<td><img src="image1" alt="CELL-11-SERVED samples-CQI" /></td>
<td><img src="image2" alt="CELL-12-SERVED EDGE samples-CQI" /></td>
</tr>
<tr>
<td>Macro interf.</td>
<td><img src="image3" alt="CELL-10-SERVED samples-CQI" /></td>
<td><img src="image4" alt="CELL-7-SERVED EDGE samples-CQI" /></td>
</tr>
<tr>
<td>Power degr.</td>
<td><img src="image5" alt="CELLS-[9,10,11,12]-CQI" /></td>
<td><img src="image6" alt="CELL-11-CENTER samples-CQI" /></td>
</tr>
</tbody>
</table>

Small cell networks, self-healing and context-awareness - October 2017 – Bologna, Italy
Discussion:

- How to measure the quality of a diagnosis system?
Many possible FOMs (Figures of Merit)

- **Distinguishing the cases:**
  - **Type I error rate or false positive ratio:** the percentage of erroneous positives obtained for a cause with respect to the total number of periods where the cause is not really present.
  - **Type II error rate or false negative ratio:** the percentage of periods where the real cause is not diagnosed over the number of periods where it is present.
  - **Inconclusive rate:** defined as the percentage of periods where diagnosis could not be performed.

- **Without distinction:**
  - **Diagnosis error rate (DER):** measured as the percentage of samples incorrectly classified over the total number of diagnosed periods, independently of the particular cause.
  - **Inconclusive rate (IN):** Percentage of samples not evaluated for lack of data.
Evaluation - Results

- Comparative between classic and contextualized-based approaches
  - Cell 11.
Evaluation - Results

- Comparative between classic and contextualized-based approaches
  - Highly improved performance. Higher with fallback technique and in cells highly affected by the macro interference, in open areas and with more users.

Discussion:

- Real positioning methods have inaccuracies. How to model them in our simulator?
Effects of localization inaccuracies

- Contextualized indicators - detection performance
  - Outperforms previous systems even for high localization error (>5 meters).

\[
\begin{align*}
\epsilon_x^m &= N(\mu, \sigma) \\
\epsilon_y^m &= N(\mu, \sigma)
\end{align*}
\]
Index

1. Introduction
2. Management architecture for context-aware SON
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Motivation

- Sleeping cell problem – catatonic
  - The cell is not able to serve users but that does not impact OAM.
  - Causes: HW radio failure, inability to load config.

- Classic
  - Throughput, call blocks, drops → might not be impacted till peak hour.
  - Handovers, mobility → event related.
  - SINR based → dependent on network load.
  - RSS → again not clear impact.

→ Application of RSS-based contextualized indicators.
Discussion:

- How to estimate geographically the area of a cell? → how to associate any position \((x,y)\) as being part of the area of a cell?
Radio info application – AOIs (I)

**Areas of Interest (AOIs)**

-_restrict the scope to relevant areas
- Sleeping cells → Most affected: Coverage and Center (ECov & ECent)
  - Expected SINR-based → dependent on network load.
  - Expected RSS-based.

\[
ECov(cell_i) = \{(x, y) \in E^2 | \widehat{RSS}(x, y, z, cell_i) > \widehat{RSS}(x, y, z, cell_j), \forall i \neq j\}
\]

\[
ECent(cell_i) = \{(x, y) \in E^2 | \widehat{RSS}(x, y, z, cell_i) > \widehat{RSS}(x, y, z, cell_j) + \Delta RSS_{cent}, \forall i \neq j\}
\]

- Analysis of the approximation depending on available information

<table>
<thead>
<tr>
<th>AOI calculation</th>
<th>Required information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic (no location / AOIs)</td>
<td>-</td>
</tr>
<tr>
<td>Test campaign</td>
<td>UE positions, positions during radiomap gathering</td>
</tr>
<tr>
<td>Site-specific detailed propagation</td>
<td>UE positions, BSs positions, transmitted power, obstacles,</td>
</tr>
<tr>
<td></td>
<td>walls, propagation conditions</td>
</tr>
<tr>
<td>Simple log-distance path loss</td>
<td>UE positions, BSs positions, transmitted power</td>
</tr>
</tbody>
</table>
Areas of Interest (AOIs)

- Log-distance path loss.
  
  \[ E_{Cov}(cell_i) = \left\{ (x, y) \in E \middle| \frac{d((x, y, z), cell_i)}{P_{tx}^{1/\alpha}(cell_i)} < \frac{d((x, y, z), cell_j)}{P_{tx}^{1/\alpha}(cell_j)}, \forall i \neq j \right\} \]

- Multiplicatively Weighted-Voronoi tessellation → complex.

- Circular center (and coverage if not equal transmission power).

  \[ R_{cov}(cell_i) = \min_{\forall i \neq j} \left( \frac{d(cell_i, cell_j)}{1 + \left( \frac{P_{tx}(cell_j)}{P_{tx}(cell_i)} \right)^{1/\alpha}} \right) \]

  \[ R_{cent}(cell_i) = k_R * R_{cov}(cell_i) \]

  \[ \Delta RSS_{cent} = 10 \log \left( \frac{k_R}{1 + (1 - k_R) \left( \frac{P_{tx}(cell_j)}{P_{tx}(cell_i)} \right)^{1/\alpha}} \right) \text{ dB} \]
**Weight functions**

- Defined for the AOI of each cell
- Relevance of individual samples
  - Expected RSS-based in normal conditions.
  - Same approximations.

\[
\begin{align*}
  w_{\text{AOI}}(x, y) &= \begin{cases} 
    \frac{P_{tx}(\text{cell}_i)/P_{tx}(\text{cell}_\text{dom})}{d((x, y), \text{cell}_i)/d((x, y), \text{cell}_\text{dom})^\alpha} & \text{if (x,y) inside AOI} \\
    0 & \text{otherwise}
  \end{cases} 
\end{align*}
\]

- Calculate metric for a particular AOI, and use it for detection
  - ECov/ECent-RSS 5th_percentile
Detection algorithm - Concept

- Distributed approach: each cell analyzes their served UEs in the areas of their neighbors.
  - The detection decision is performed by combining information from the different cells of the impacted set $cells_{imp}^i$: the cell and its neighbors.
Detection algorithm - Individual stage

- **Individual stage**
  - For each cell (maybe faulty), each cell $j \in \text{cells}_i^{imp}$ compute the metrics $F_{ij}^{AOI}$ associated with their served UEs in cell $i$ AOIs, their conditional probabilities $\hat{p}(F_{ij}^{AOI} = f_{ij}^{AOI}[t]|\text{Normal})$, $\hat{p}(F_{ij}^{AOI} = f_{ij}^{AOI}[t]|\text{Sleeping})$.
  - and confidence level:
    $$\Omega_F[t] = (|M_F[t]| < |M|_{th}) \cdot \varphi_F[t] \cdot \Psi(F)$$

$$\varphi_F[t] = \frac{1}{\varphi_F[t]} \sum_{s=1}^{M_F[t]} w_F(\gamma_{xyz}[s]),$$

$$\Psi(F_{ij}^{AOI}) = H(\hat{p}(F|\text{Normal}_i), \hat{p}(F|\text{Sleeping}_i))$$
Detection algorithm - Distribution stage

- Compute the posterior probability $\rightarrow$ detection
  \[
  \frac{\hat{p}(Normal_i)}{\hat{p}(Sleeping_i)} \prod_{\forall F \in F} \left( \frac{\hat{p}(f[t]|Normal_i)}{\hat{p}(f[t]|Sleeping_i)} \right)^{\Omega_F[t]} < 1 \rightarrow cell_i \text{ is faulty},
  \]
- After: consensus, alert to OAM, diagnosis, compensation, recovery...
- LTE system level simulator.
- UE 1s reporting period, 1min observation period.
- 200 normal and 200 faulty periods per cell, 50 periods training set.
- Classic performance indicators (e.g. CBR) are not useful for detection.

### Evaluation - Set-up

<table>
<thead>
<tr>
<th>Normal periods</th>
<th>Failure periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH NUMBER OF USERS</td>
<td>12 users/cell</td>
</tr>
<tr>
<td>MEDIUM NUMBER OF USERS</td>
<td>7 users/cell</td>
</tr>
</tbody>
</table>

- CBR per cell [%]
- Period [minutes]
**Evaluation - Results**

- **RSS Classic vs Location-based**
  - Narrower AOIs show higher statistical impact of the failure.
Discussion:

- How to measure the quality of a detection system?
Evaluation - Detection performance

- In detection we only have two “cases”.
- Different possible FOMs (Figures of Merit)
  - False negative rate (FN), defined as the percentage of all faulty periods identified as normal;
  - False alarm rate (FA), sometimes also referred in detection problems as false positive, the percentage of the normal periods identified as faulty;
  - Inconclusive rate (IN) or the percentage of periods where there are no UE RSS measurements in the considered AOI and no detection is performed.
Evaluation - Detection performance

- **Combinations**
  - Local, centralized, distributed.
  - Non-location (NL) or using AOI – center or coverage.

- **Detection performance**
  - FN, FA, IN.
  - Outperforms classic mechanisms except for cell 12 – surrounding by walls → more complex AOI definitions for those cases.
Sleeping cell case - detection performance

- Outperforms previous systems even for high localization error (>5 meters).

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Conclusions

- The identification of the main characteristics and challenges of dense small cell networks from the point of view of the application of classic SON mechanisms and, especially, self-healing.

- A context-aware OAM architecture for integrating UE context information in cellular SON systems.

- A context-aware self-healing framework to support failure management based on both network data and context information, creating a general approach for those mechanisms.

- Contextualized indicators as a novel approach to allow the integration of context-variables and classic performance metrics (e.g. KPIs).

- Novel context-based self-healing mechanisms to tackle different detection and diagnosis use cases.
Possible work lines

- Context variables and sources: end-user applications, preferences...
- New inference mechanisms and data analysis.
- Feature selection and extraction.
- Additional trials and testbeds.