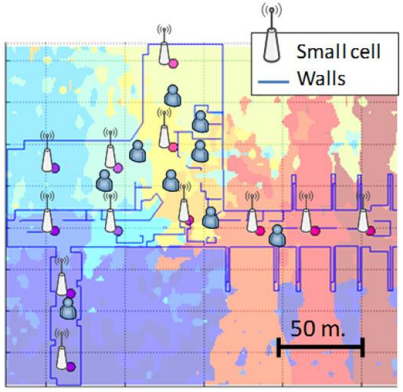
Small cell networks, self-healing and context-awareness



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Bologna, Italy (October 2017)

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Motivation

Small cell networks, self-healing and context-awareness

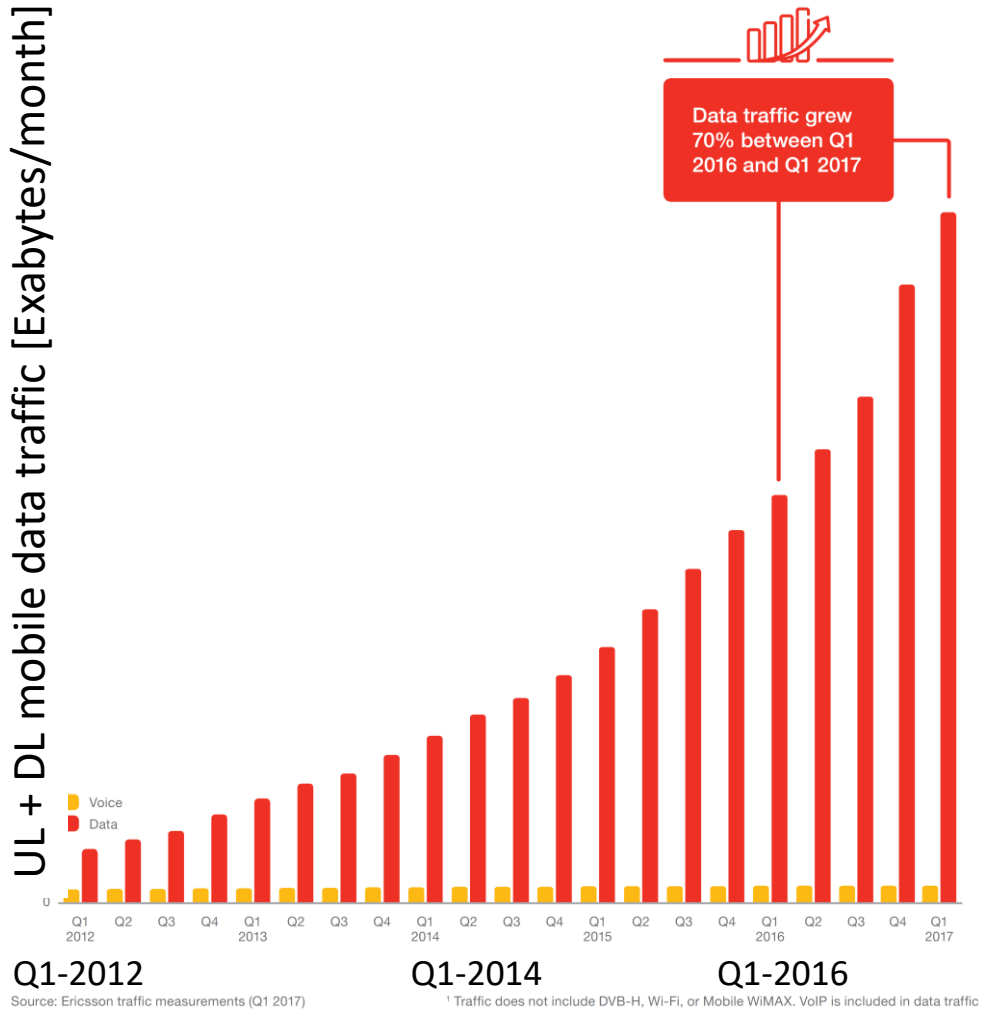
Motivation

Small cell networks, self-healing and context-awareness

Motivation – Growing cellular demand

INT

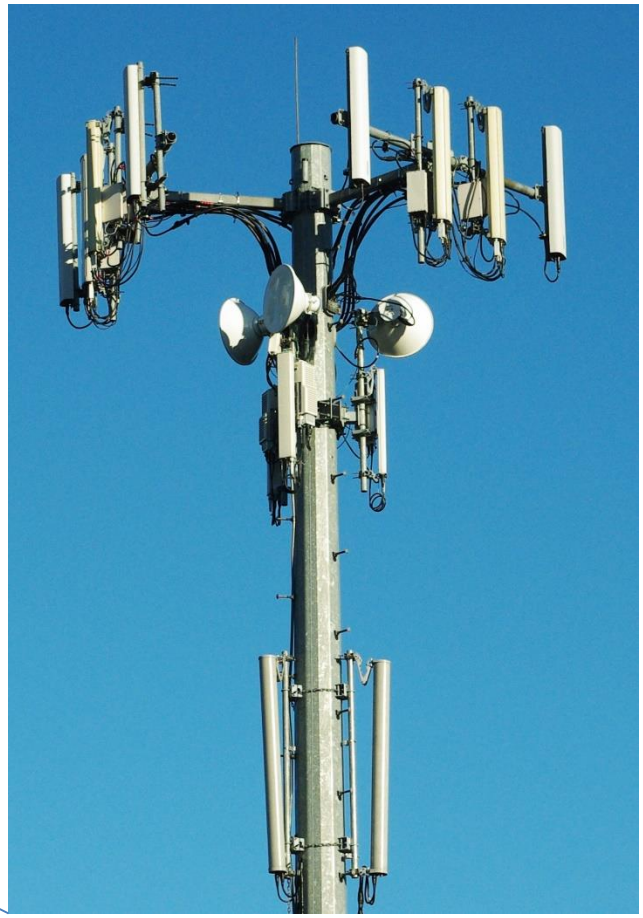
- **Growing demand for mobile communication**
  - Increased number of users and data traffic.
- **Flat Rate**
  - Reduced returns.
- **Mechanisms to meet demand**
  - New technologies.
  - Higher BW in higher frequency bands.
  - More frequency reuse.



Motivation – Small cells

INT

- **The classic macro cell-tower**
  - Visible, large.

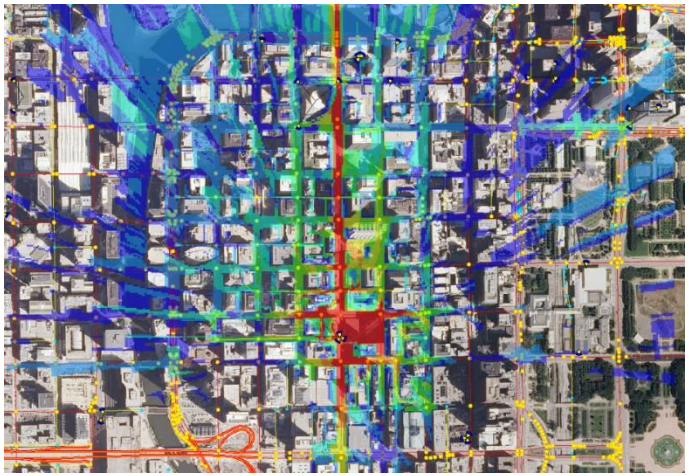


Motivation – Small cells

INT

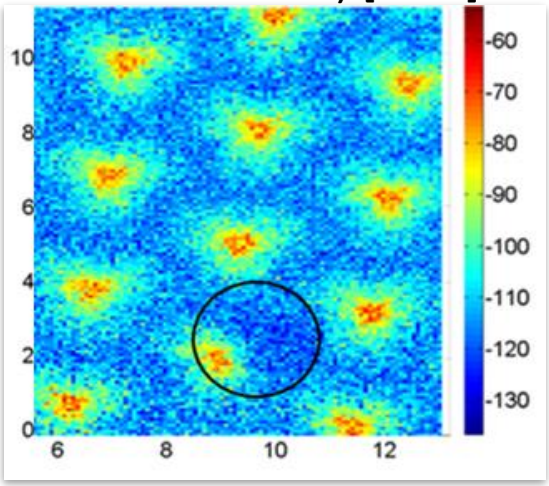
- **The classic macro cell-tower**
  - Tri-sectorial.
  - Coverage of Kms - hundreds of meters. Ptx=40 W (typ.).
  - Expensive, high investment, costly maintenance.
  - **Coverage issues at indoors, urban valleys → worst with increase. freq.**

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

RSRP (Reference Signal Receive Power) [dBm]



[km]

Source: Ana Gómez Andrades

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

?

Motivation – Small cells

INT

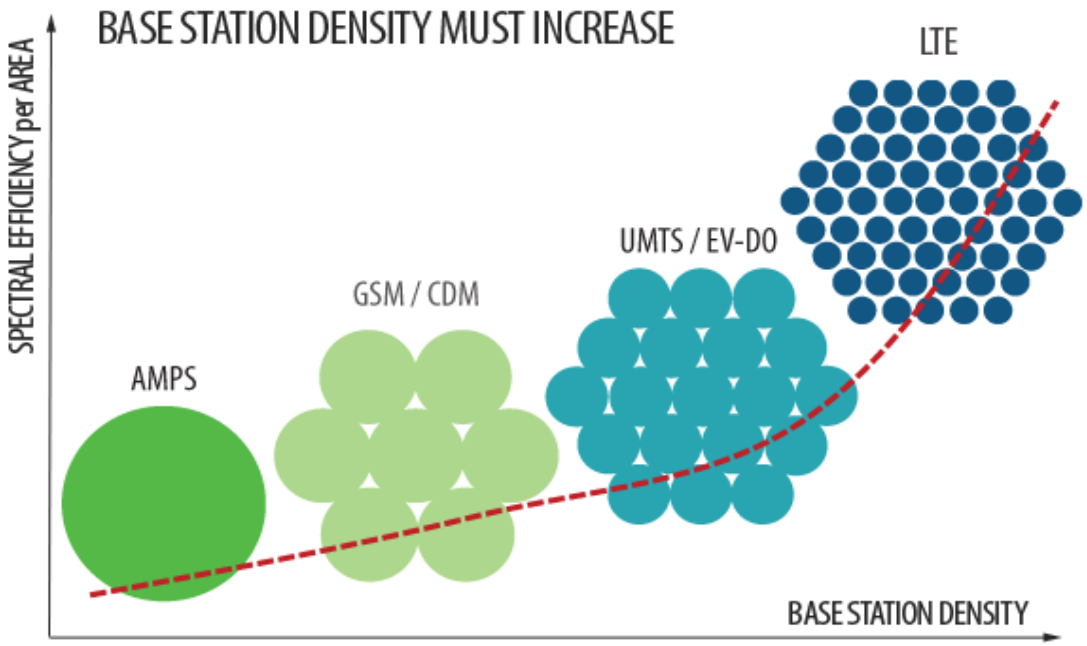
- **Discussion:**
  - Why increasing frequency?
  - What is the issue in higher freqs.?

- 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

INT

- **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

INT

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

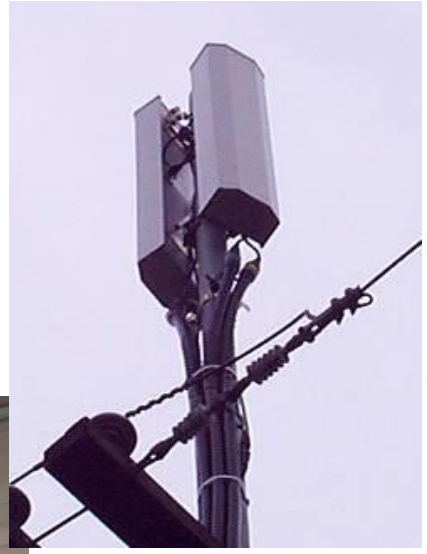
https://www.mobileeurope.co.uk/trends/small-cells?limit=50&start=100

http://blog.spidercloud.com/author/admin/page/4/

Motivation – Small cells

INT

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



http://www.geckobeach.com/cellular/cellpixs/fido_pix.php

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

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

http://www.bbox-forum.net/t8534-exclu-femtocell-bouygues-telecom-des-cet-ete

Motivation – Small cells

INT

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

http://goughlui.com/2015/07/04/salvage-hts541680j9sa00-80gb-hdd-duracell-aaa-optus-cable-card-alcatel-lucent-home-cell/

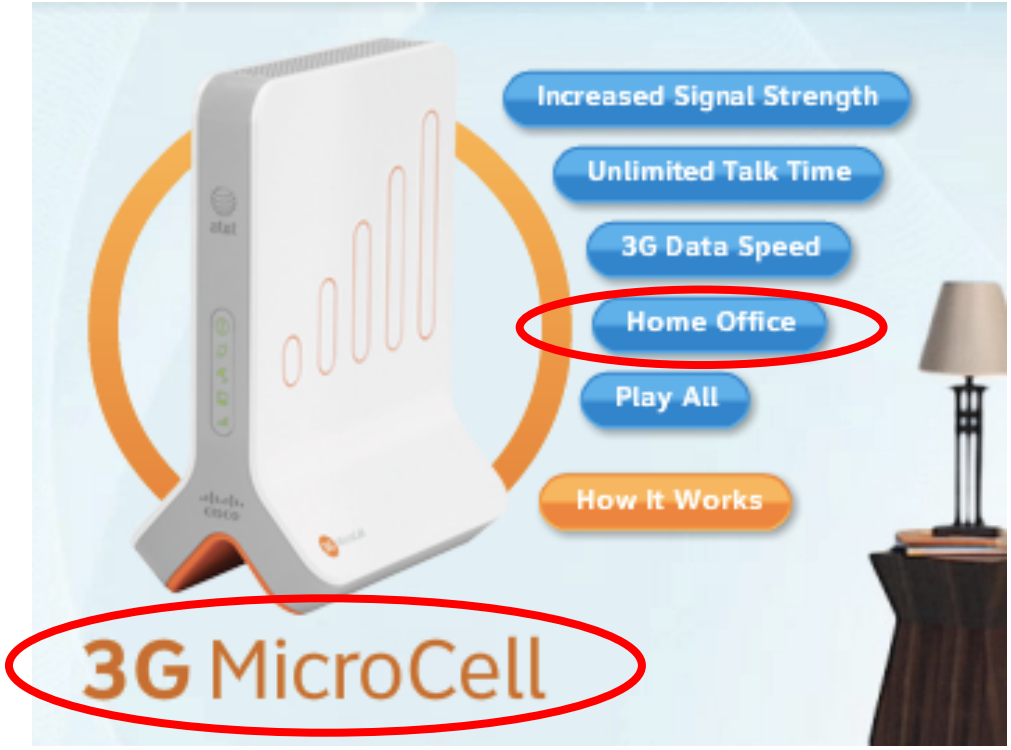
  - **Metrocell:**
    - Small cell installed in lamp post or other urban elements.

http://smallcells.3g4g.co.uk/2013/05/china-mobile-and-ericsson-deploy-gsm.html

Motivation – Small cells

INT

- **Not everyone follows the nomenclature!**



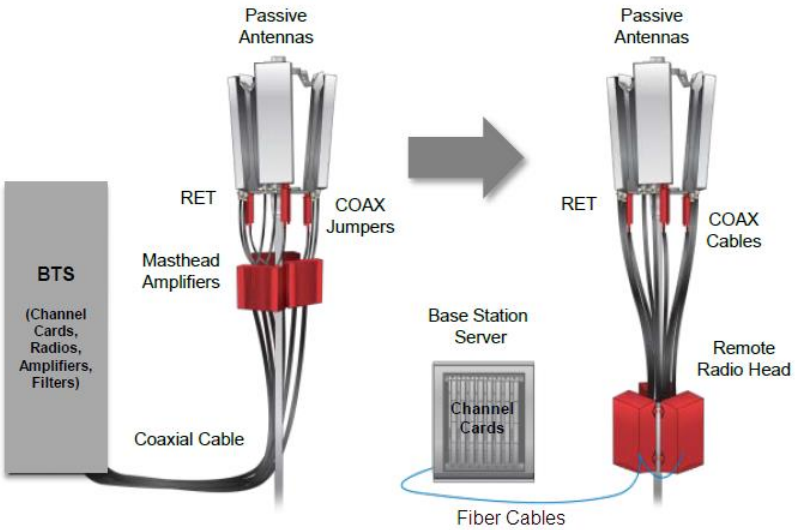
https://www.imore.com/att-microcell-boost-iphone-reception-5-markets

Joseph Thornton / Flickr

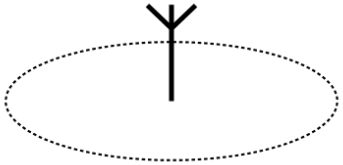
Motivation – Small cells

INT

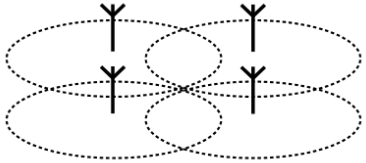
- **Other non-classical provisions**
  - Relays – retransmit.
  - Remote radio heads (RRH).
  - DAS – distributed antenna system: multi-operator.
- **The trend: centralized the radio processing.**
  - Shared base station server.
  - Synergies between stations, faster coordination.
- Not so long ago → decentralized the processing…



http://www.commscope.com/Blog/fiber-to-the-antenna/



single antenna

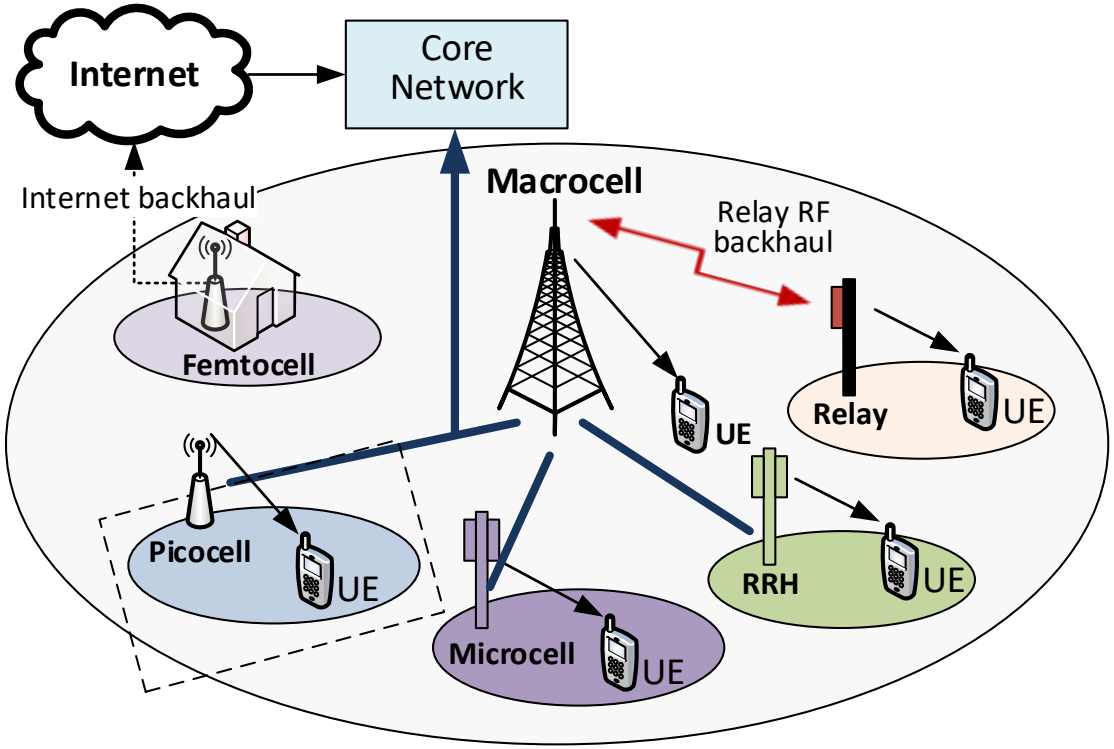


distributed antenna system

Motivation – Small cells

INT

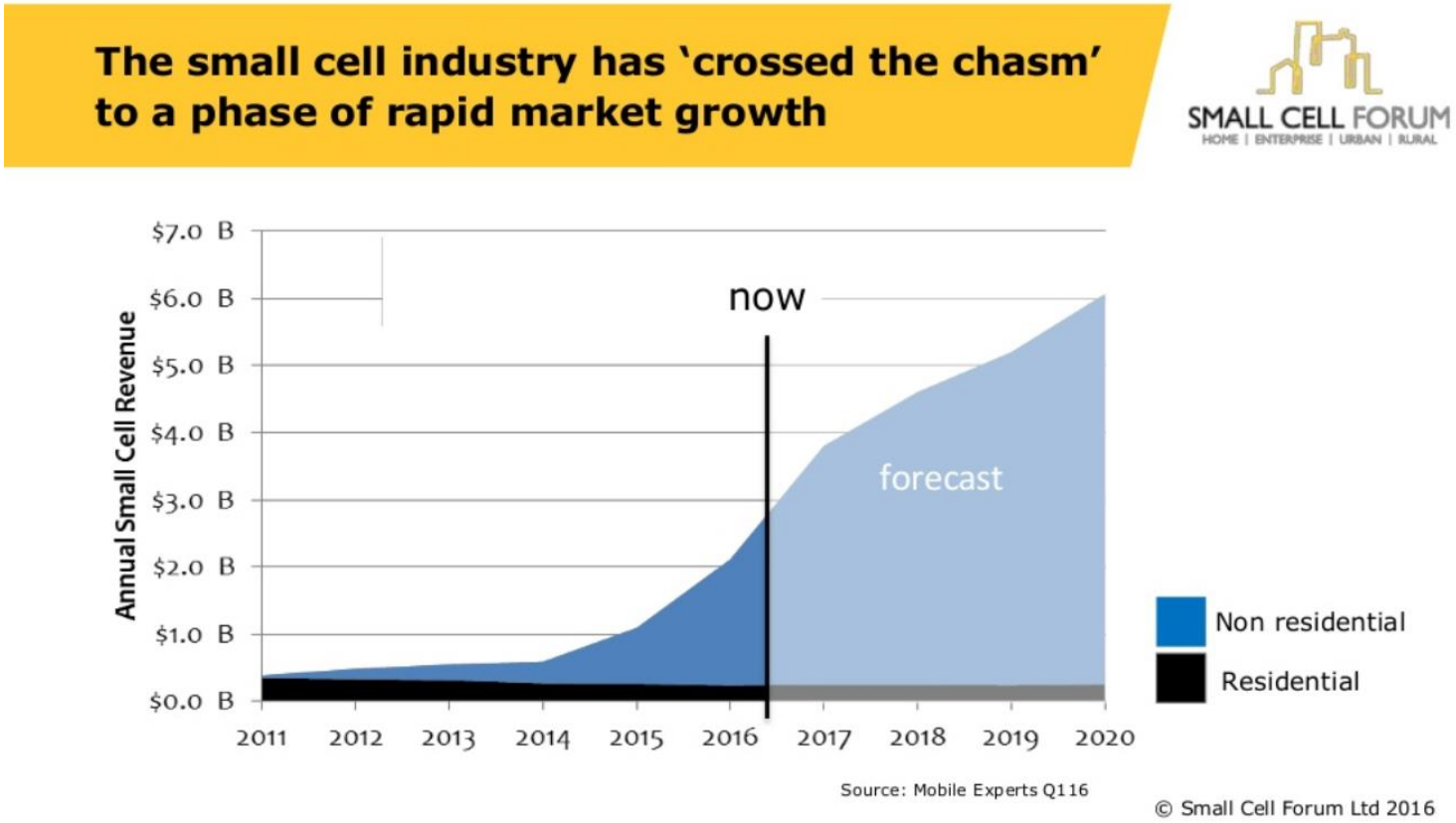
- Different deployments and technologies → heterogenous networks (HetNets)
- Many times co-located with macro and supported by its backhaul.



Motivation – Small cells

INT

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



Motivation – Small cells

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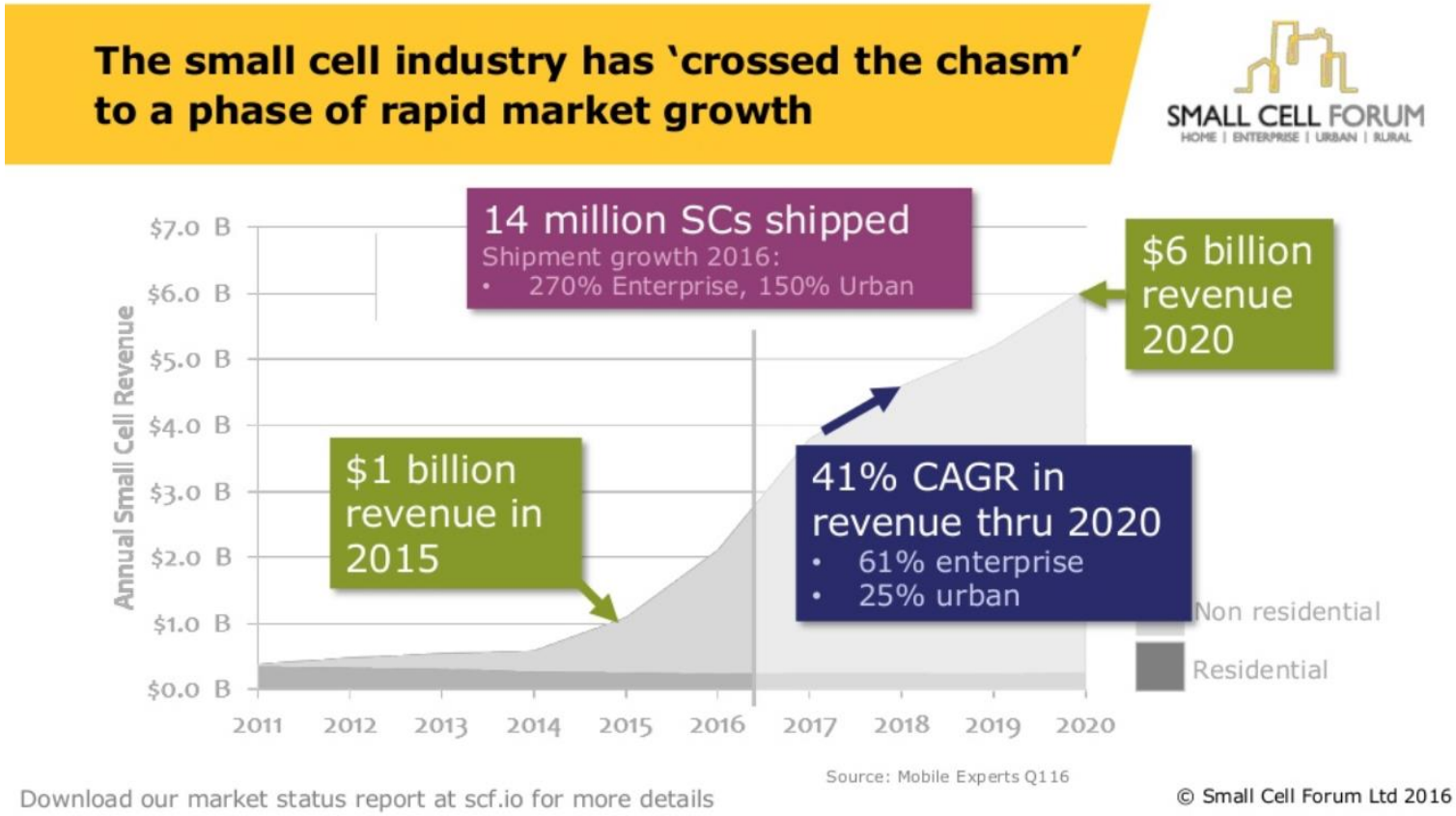


Motivation – Small cells

INT

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

http://www.tektelic.com/solutions/small-cell-solutions/

Motivation – Small cells

INT

- **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.**

Motivation

Small cell networks, **self-healing** and context-awareness

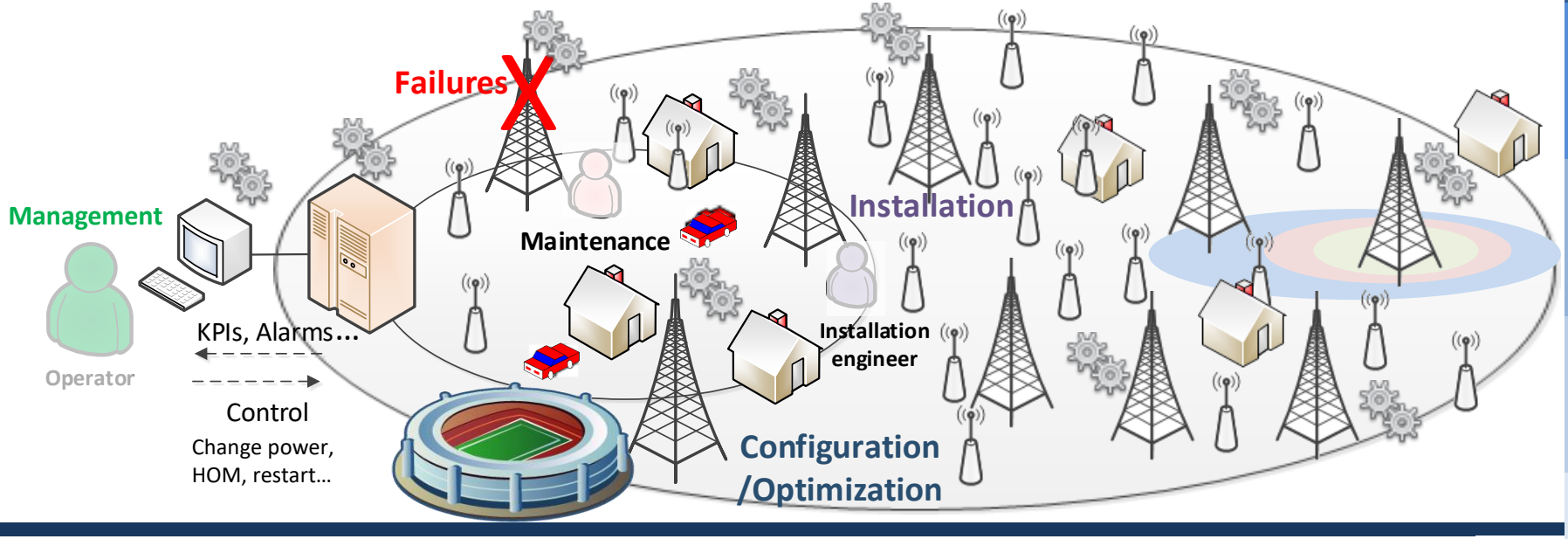
Motivation - SON

INT

Self-Organizing Networks (SON)

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

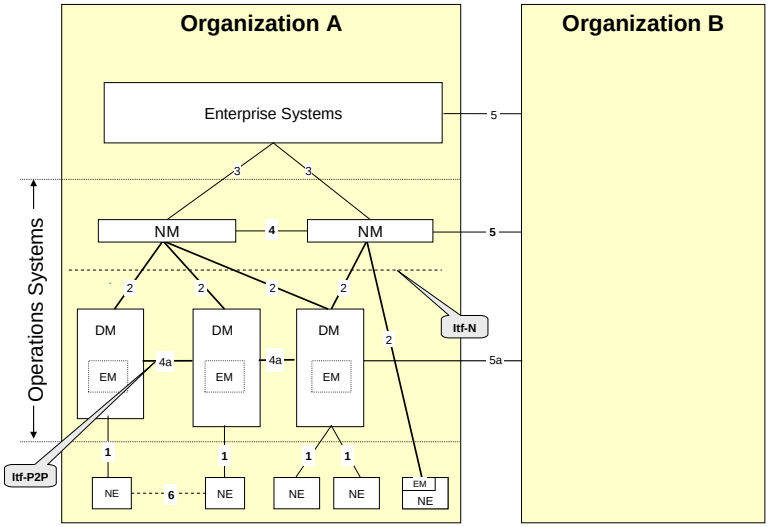
- **Main functionalities:**
  - ***Self-configuration:*** elements initial deployment.
  - ***Self-optimization:*** re-configuring parameters.
  - ***Self-healing:*** automatic failure management.



Motivation - SON

INT

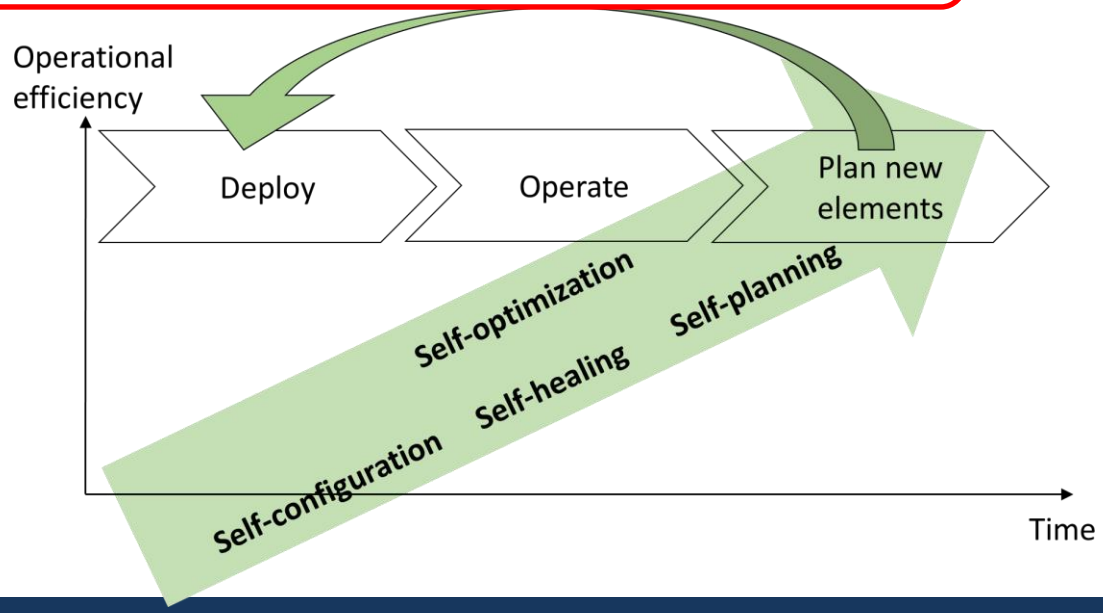
- **SON systems are implemented as part of the OAM architecture: NE, DM, NM and closer to the control plane.**
- **3GPP introduced the general SON concept and functions in the LTE standard.**
  - Qualitative manner and use cases, general scheme and requisites.
- **The specific algorithms are open for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



Motivation - SON

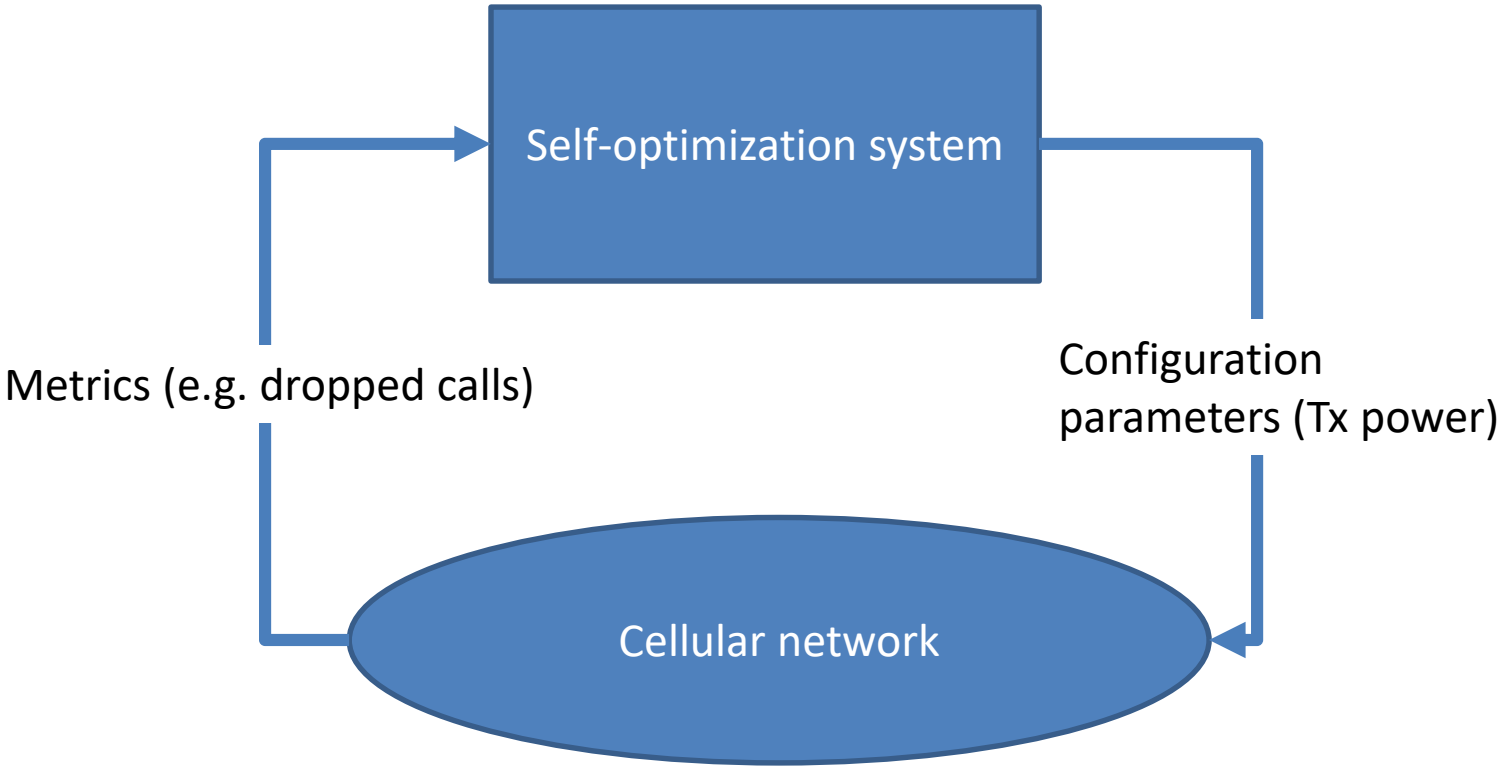
INT

- **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.

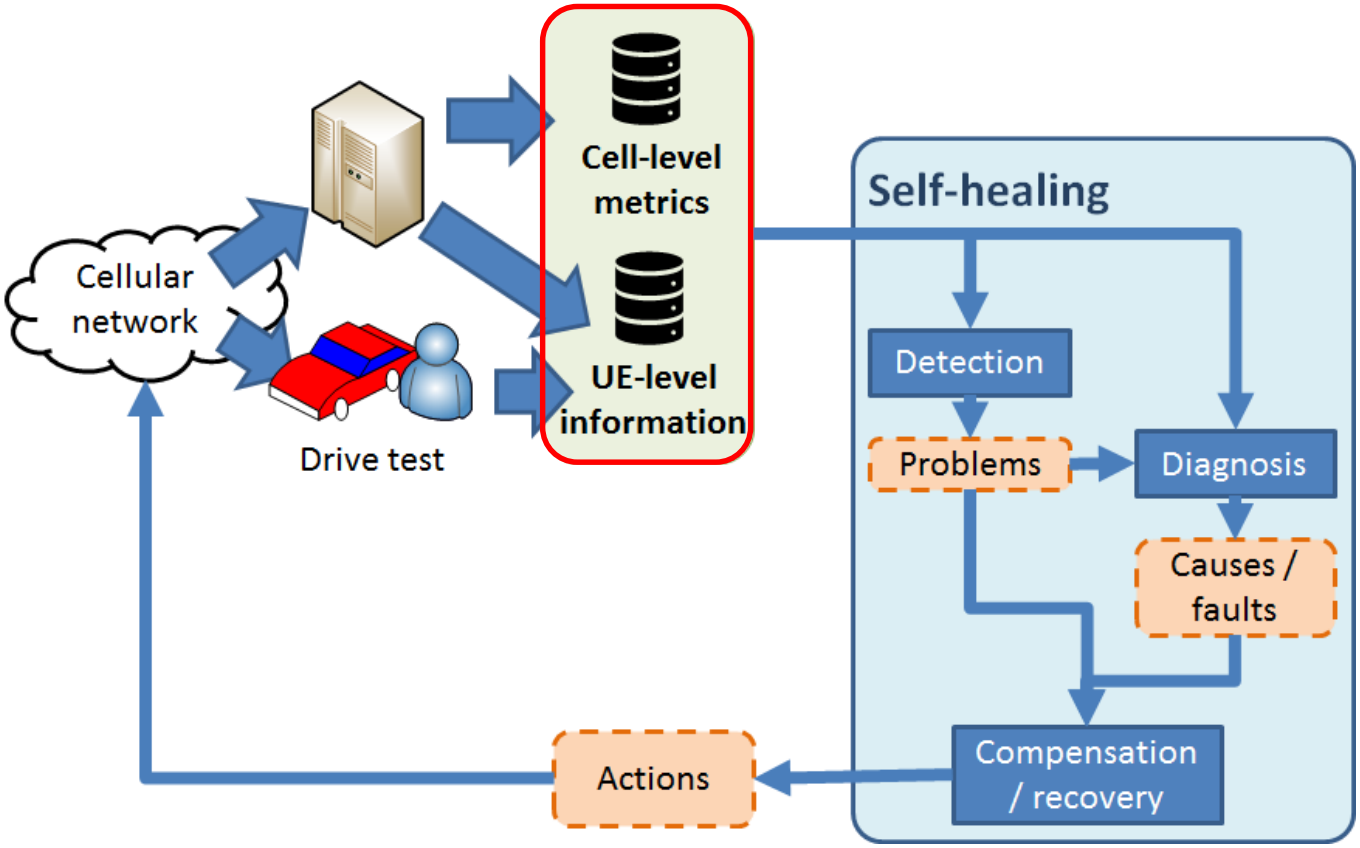


Self-optimization – General diagram

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



Self-healing – Scheme



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

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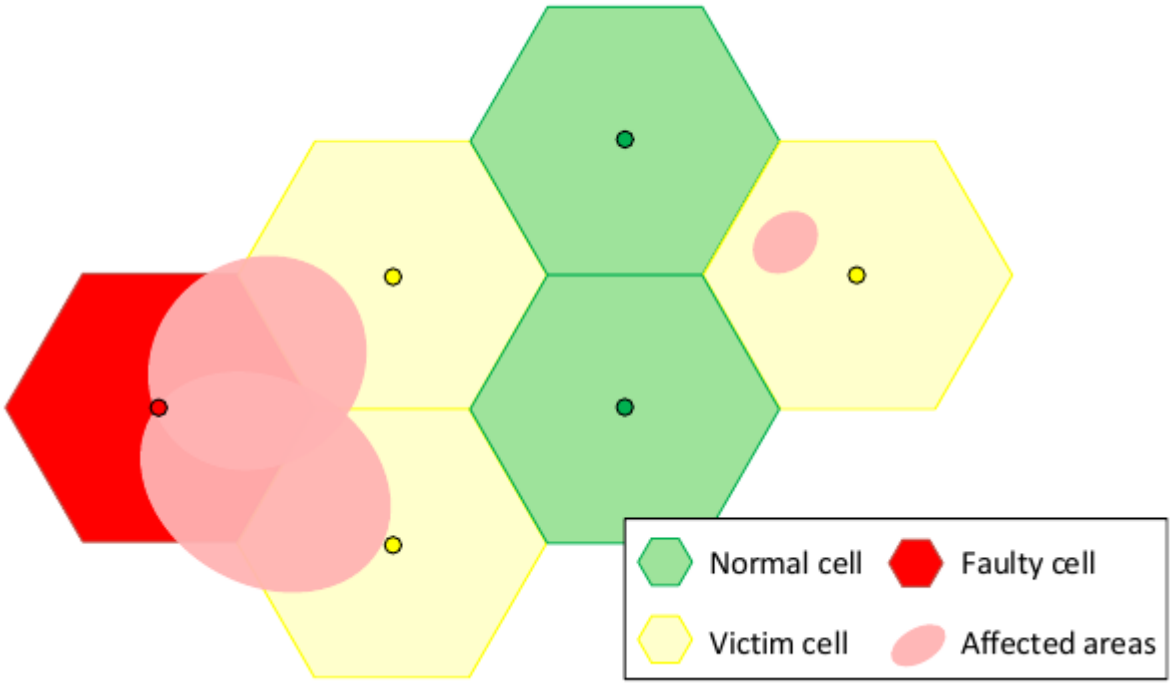
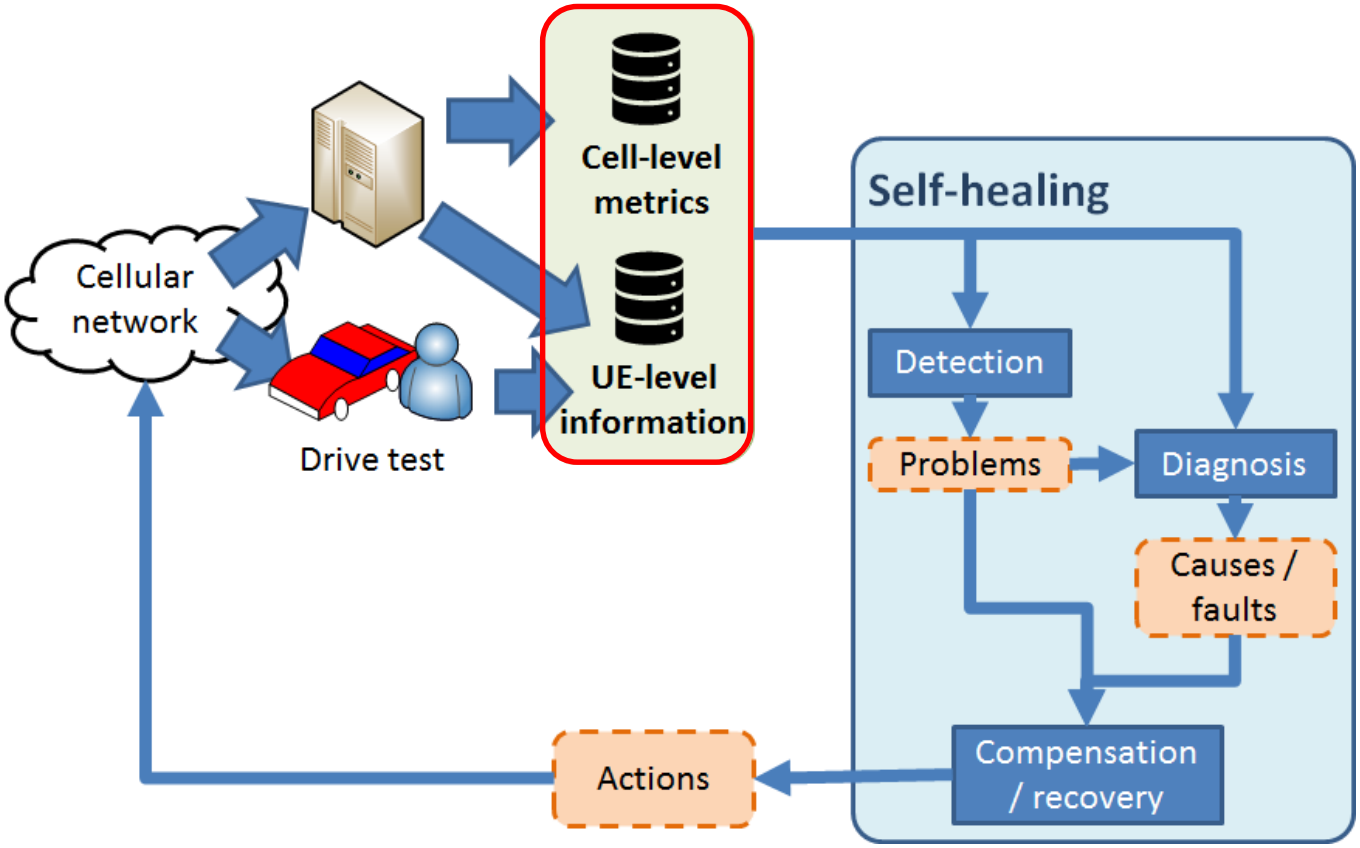
- **Cause/fault** of a problem:
  - refers to the specific software or hardware malfunction that led to the service degradation. Typical causes include base station (BS) disconnection, interference, parameters misconfiguration, failures in the BS components, etc.
- **Detection** identifies the presence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

Self-healing – Scheme

- **Problems are typically defined at cell level.**



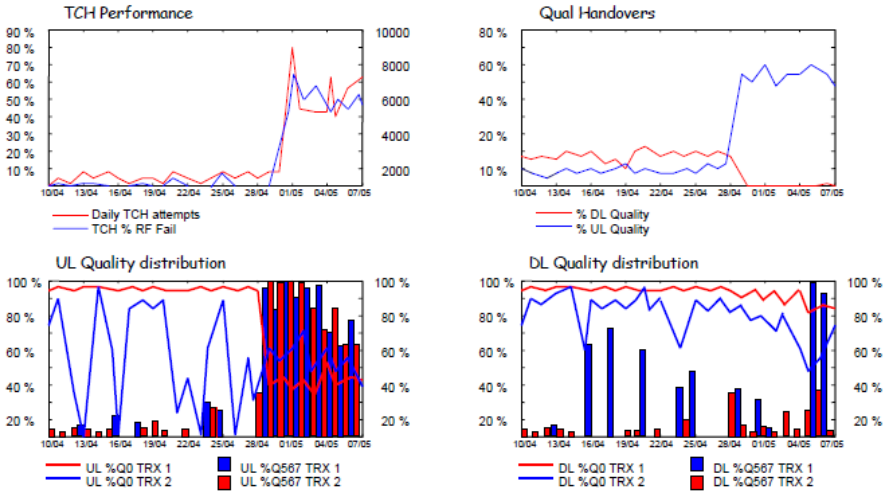
Self-healing – Scheme

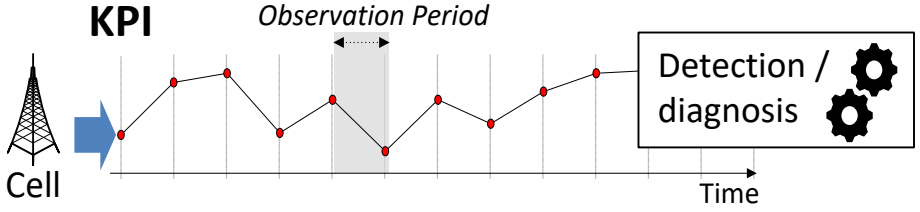


Self-healing – Sources

INT

- **Cell-level metrics**
  - Base of classical approaches: status monitoring, alarms, counters, **KPIs**.
  - KPI – key performance indicator: performance / radio measurements <u>statistics.</u>
    - Drop call rate, call blocking rate…
  - One value each observation period (e.g. 1 hour) → statistics.



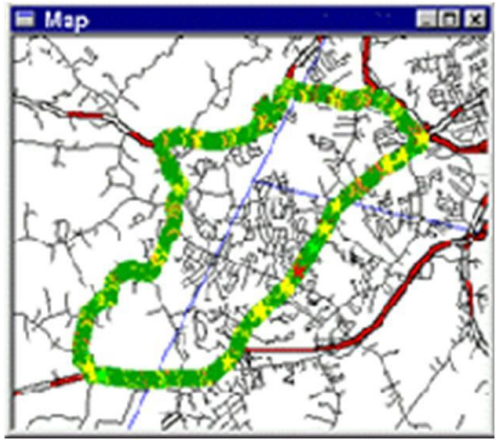


Self-healing – Sources: Drive test

INT

- **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

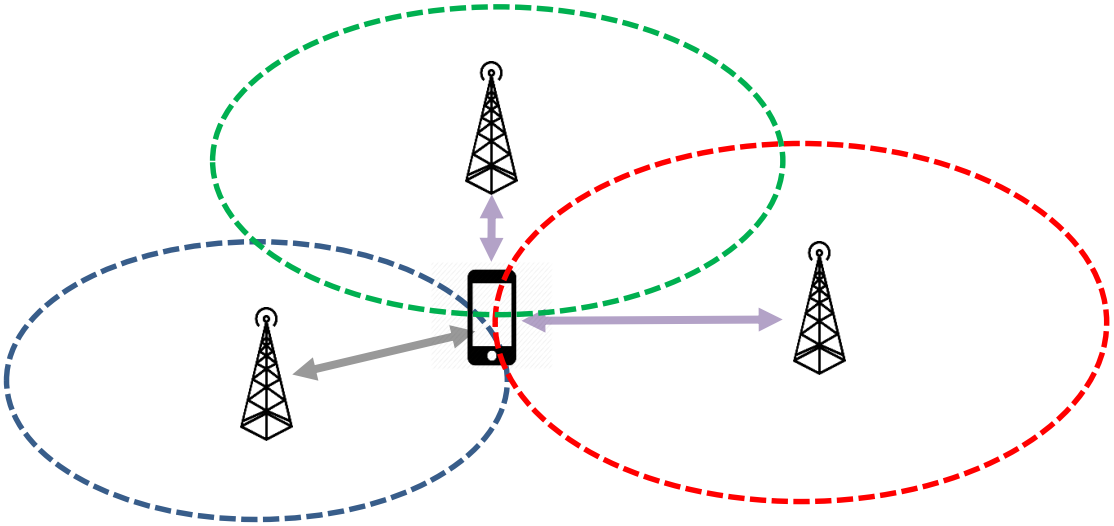


http://www.teletopix.org/gsm/drive-test-plan-procedure-and-output-for-gsm/

Self-healing – Sources: MDT

INT

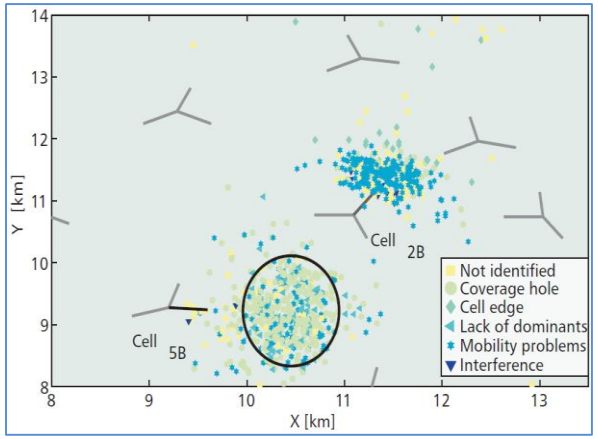
- **Minimization of Drive Test (MDT)**
- incorporated to the 3GPP standard in recent years, enriches previous trace mechanisms by adding localization information to the UE reports.
- Here, UE positions are typically estimated by means of cellular techniques, e.g. cell id, timing advance (TA), time of arrival (ToA), time difference of arrival (TDoA)...

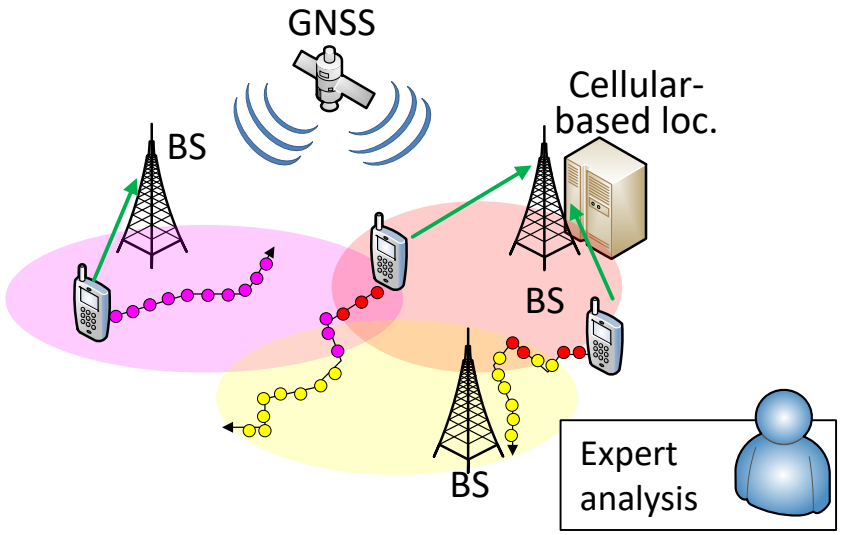


Self-healing – Sources

INT

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





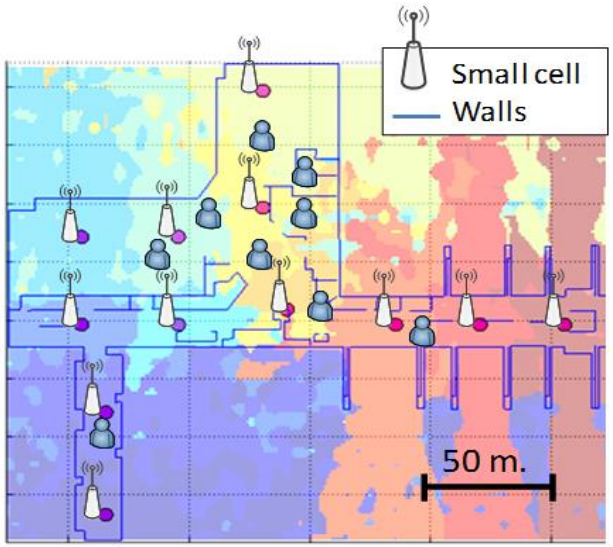
Motivation - Features and challenges

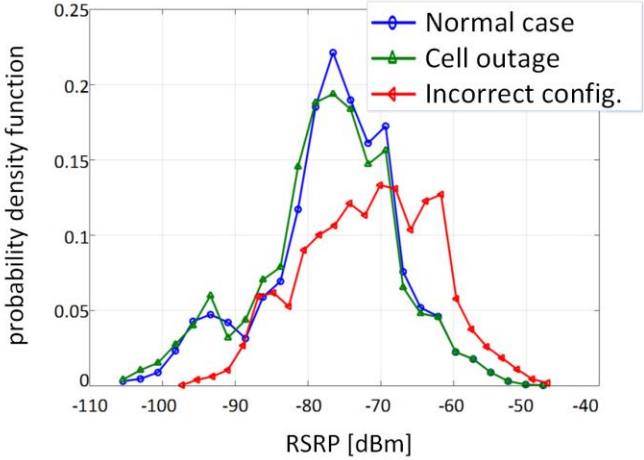
INT

- **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?





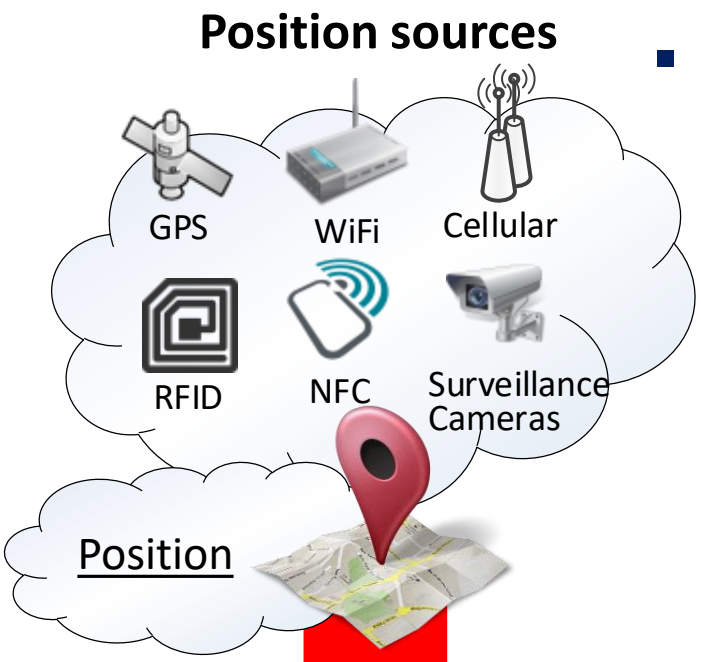
Motivation

Small cell networks, self-healing and **context-awareness**

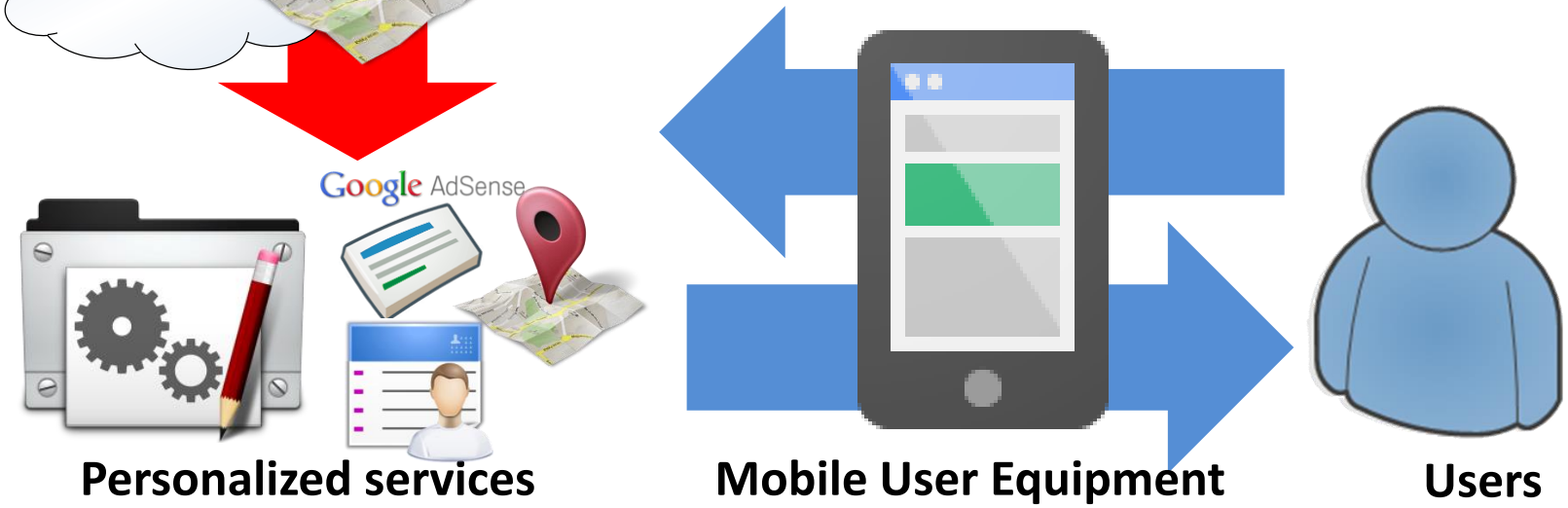
Motivation - Context variables

- **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

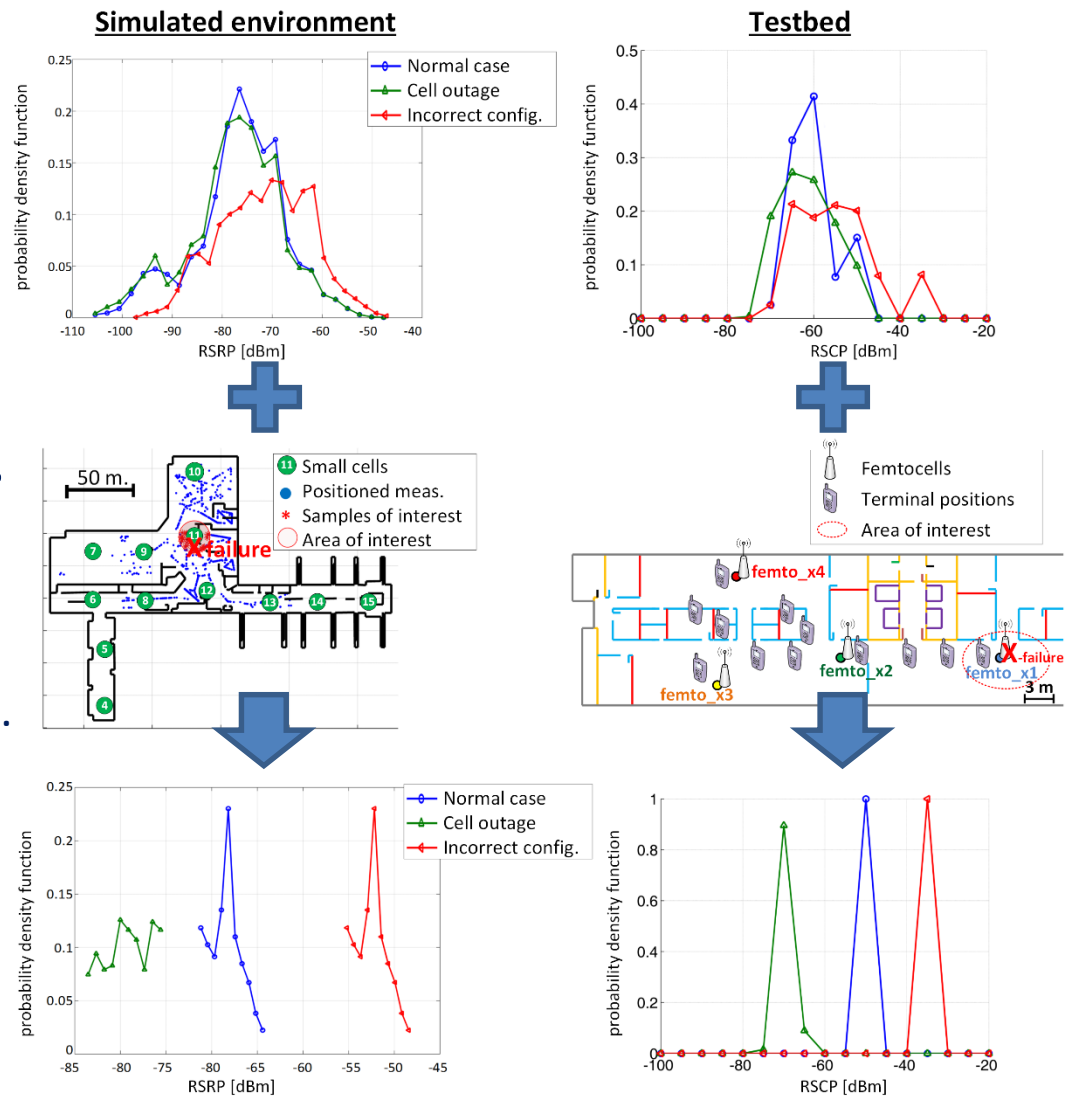


- **Indoor localization**
  - Outside GNSS coverage, macro-cellular…
  - Required for "killer apps" and personalized services.
  - Techs: WiFi, small-cellular, RFID, UWB…
  - Expected to be fully available in 5G.



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

INT

Self-Organizing Networks (SON) for Small Cells

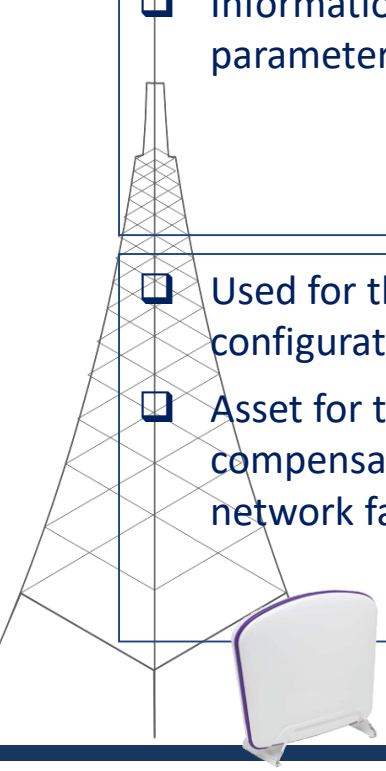
- Deployment configuration for communications (and localization).
- Information about failures, change of parameters, etc.

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.

- Used for the fine adjustment of the configuration parameters → SO
- Asset for the detection/diagnosis compensation and recovery of network failures → SH



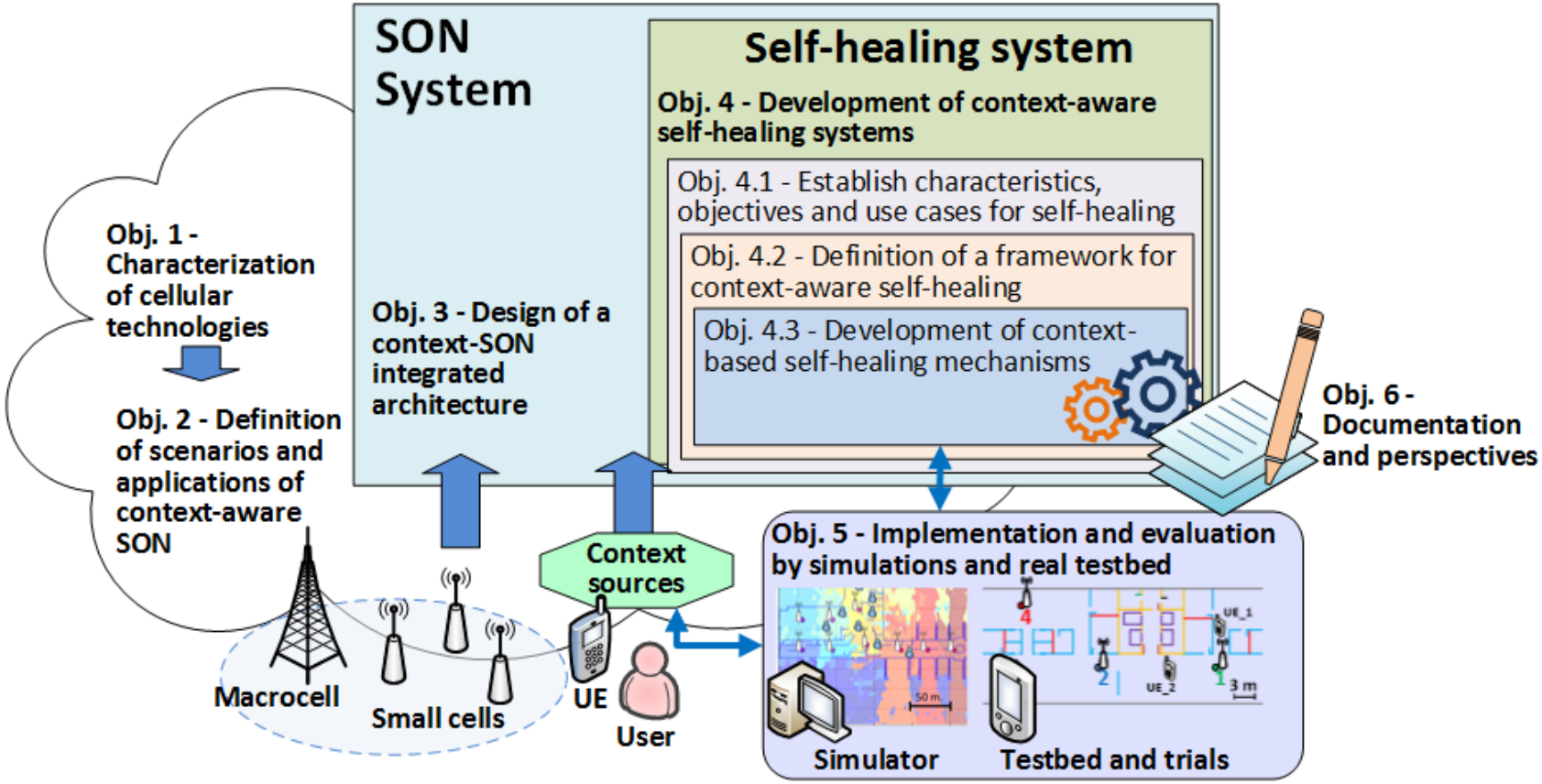
Integration SON & Positioning (II) - Issues

- **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

INT

- **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:**

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

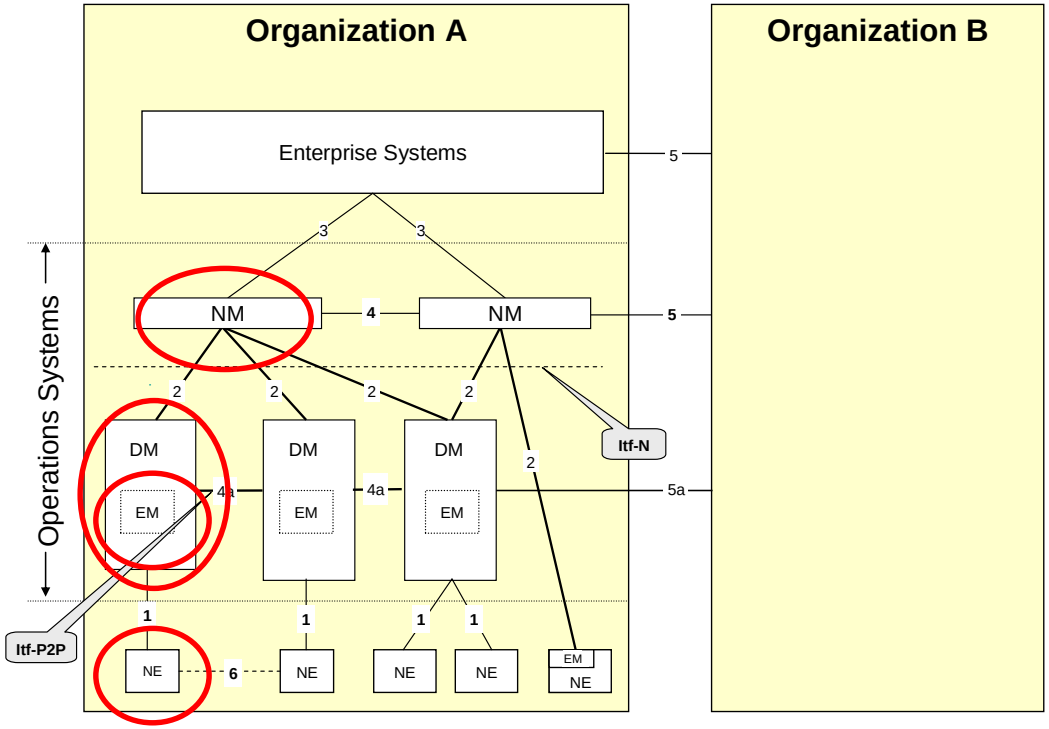
- **An architecture to bring the SON to the context level:**
  - Integration with previous OAM mechanisms and architecture.
  - Communications versatility.
  - Reduced signaling.
  - Management speed.

- **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.

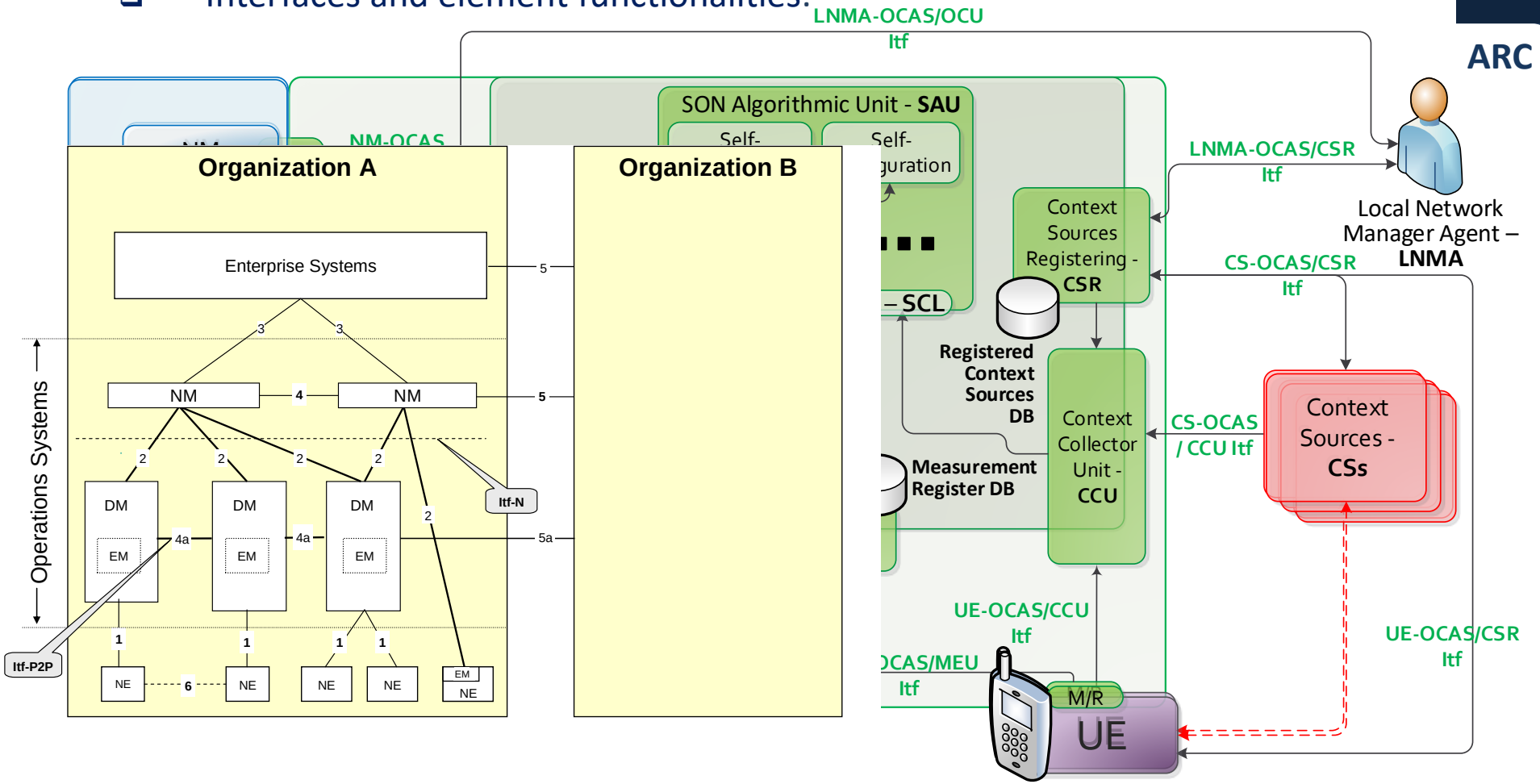
Entity	Task	Parameter abstraction	Time span
NM	Planning	Vendor independent	weeks / month
EM/DM	Network operation	Vendor independent / specific	hours/ days
NE	Element config.	All parameters	s/min



ARC

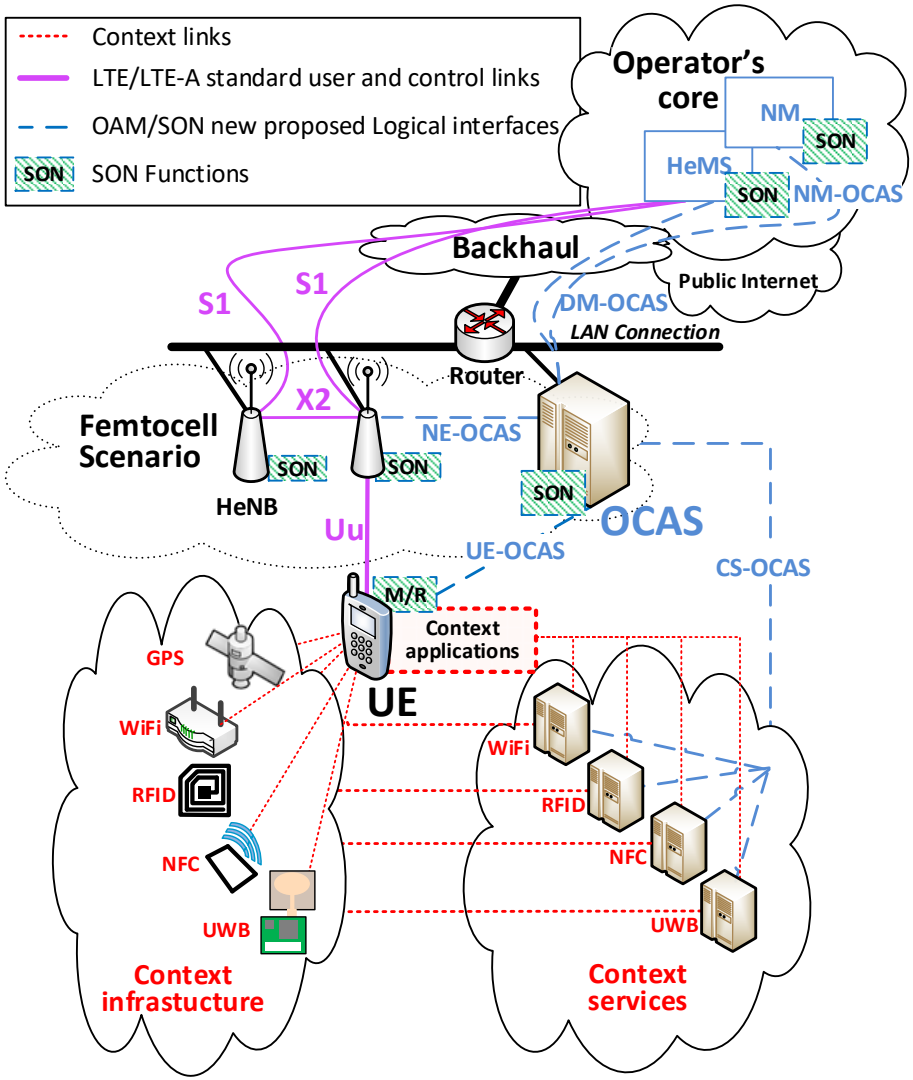
Architecture - Functional model

- **3GPP OAM plane**
  - Interfaces and element functionalities.



SON Architecture - Implementation

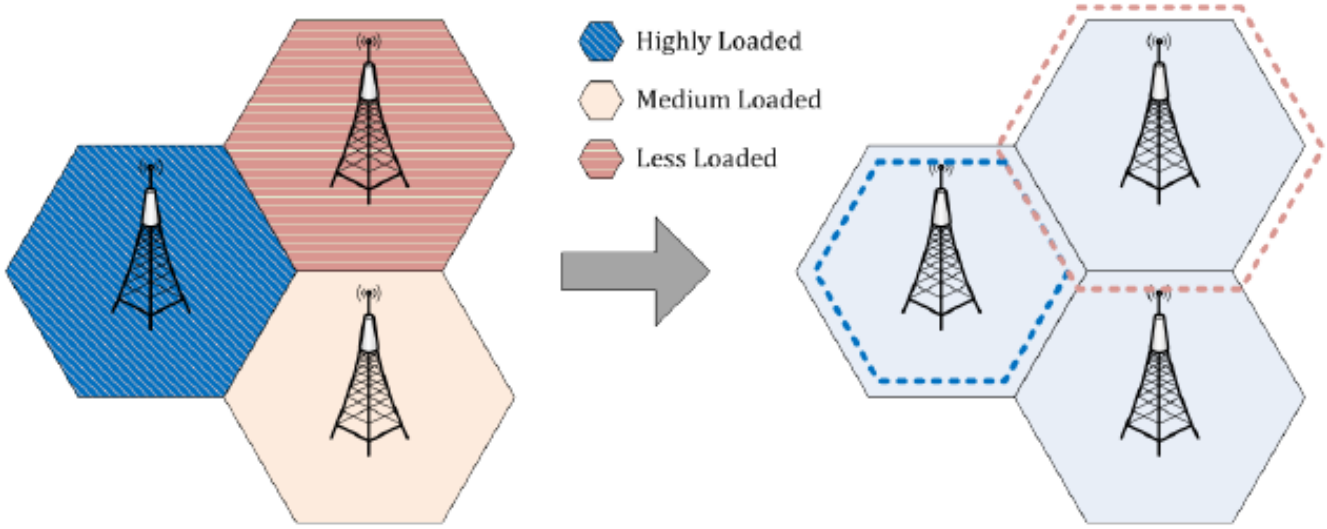
- Femtocell (non-dedicated backhaul) oriented scheme.
- Available integration in the LTE/LTE-A standard plane or over-the-top.
- Direct LAN connection and without crossing the operators' core.
- Reduced signaling.



ARC

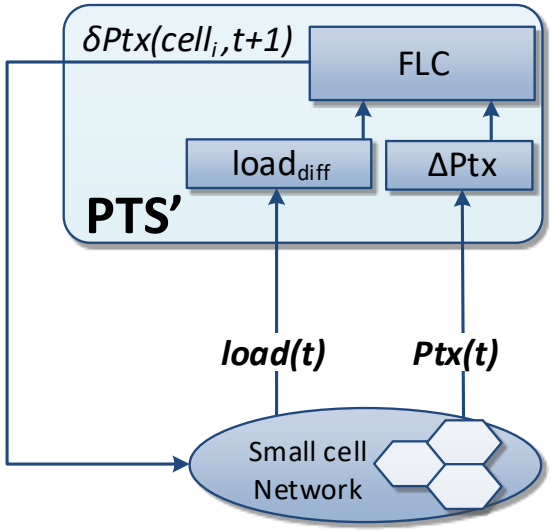
Evaluation - PTS'

- **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

$$load_{diff}(cell_i, t) = load(cell_i, t) - \frac{1}{|\boldsymbol{Adj}(cell_i)|} \sum_{\forall cell_j \in \boldsymbol{Adj}(cell_i)} load(cell_j, t),$$

- *Outputs*

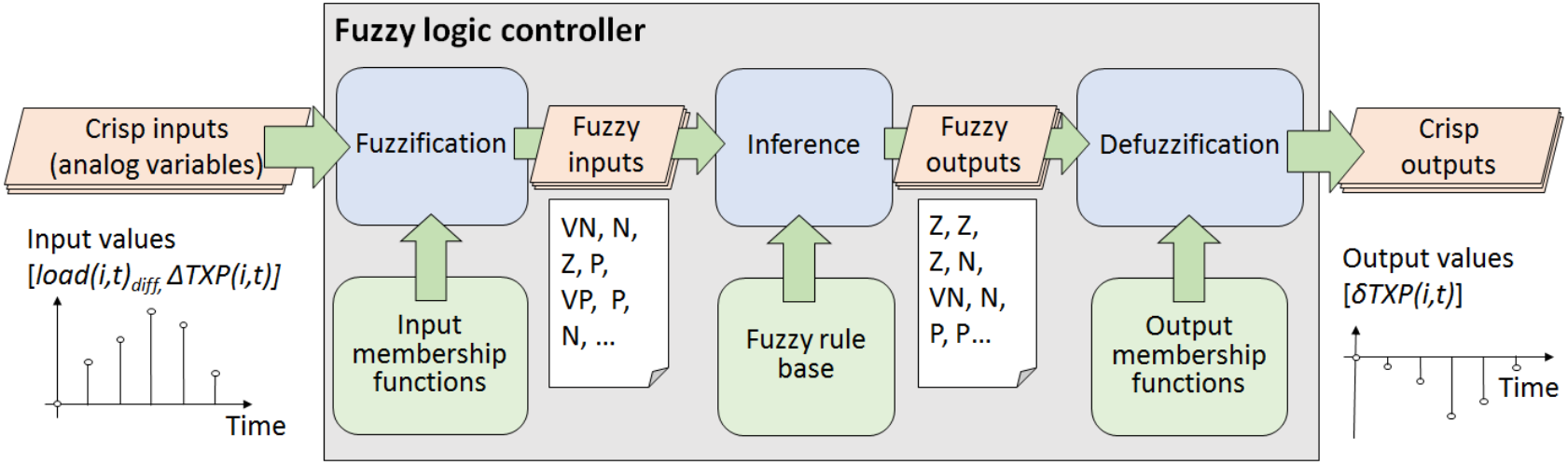
$$Ptx(cell_i, t+1) = Ptx(cell_i, t) + \delta Ptx(cell_i, t+1),$$

- **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.



*J. M. Ruiz-Aviles, S. Luna-Ramirez, M. Toril, F. Ruiz, "Fuzzy Logic Controllers for Traffic Sharing in Enterprise LTE Femtocells," in IEEE Vehicular Technology Conference (VTC) Spring 2012, Yokohama, Japan, May 2012

Evaluation - Fuzzy logic controller

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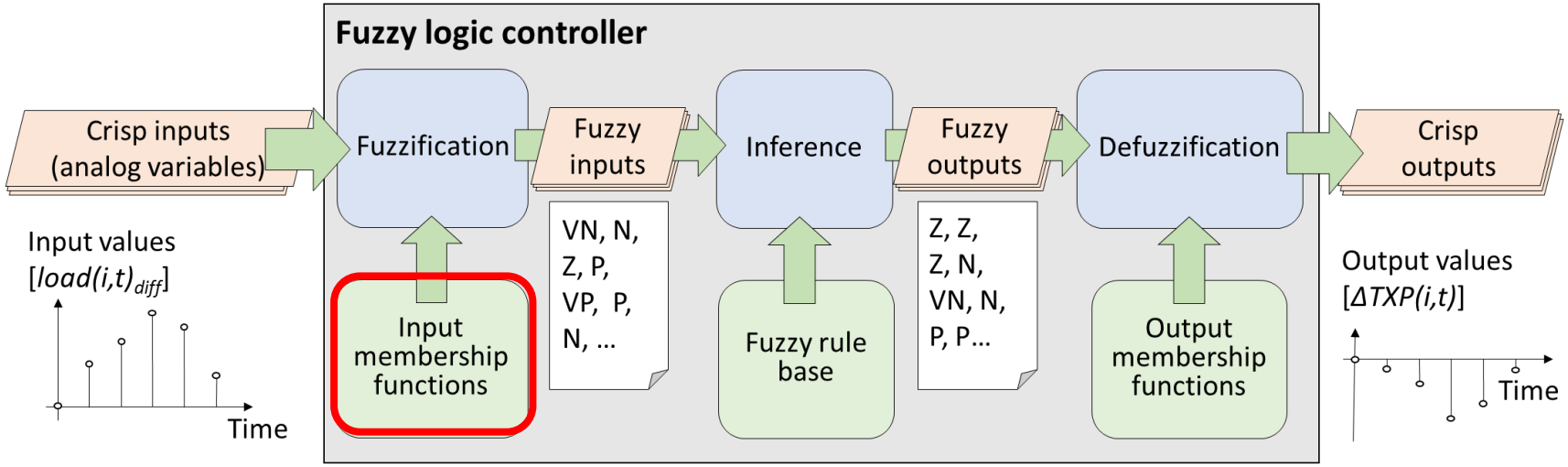
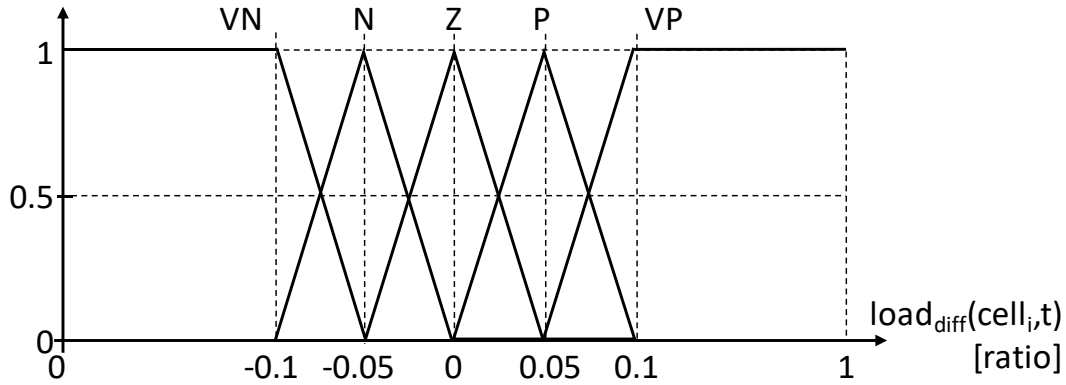
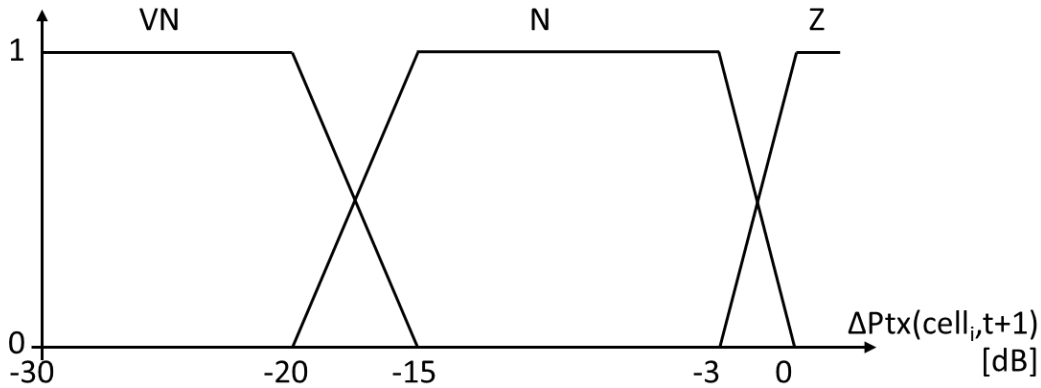


Evaluation - Fuzzy logic controller

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





Evaluation - Fuzzy logic controller

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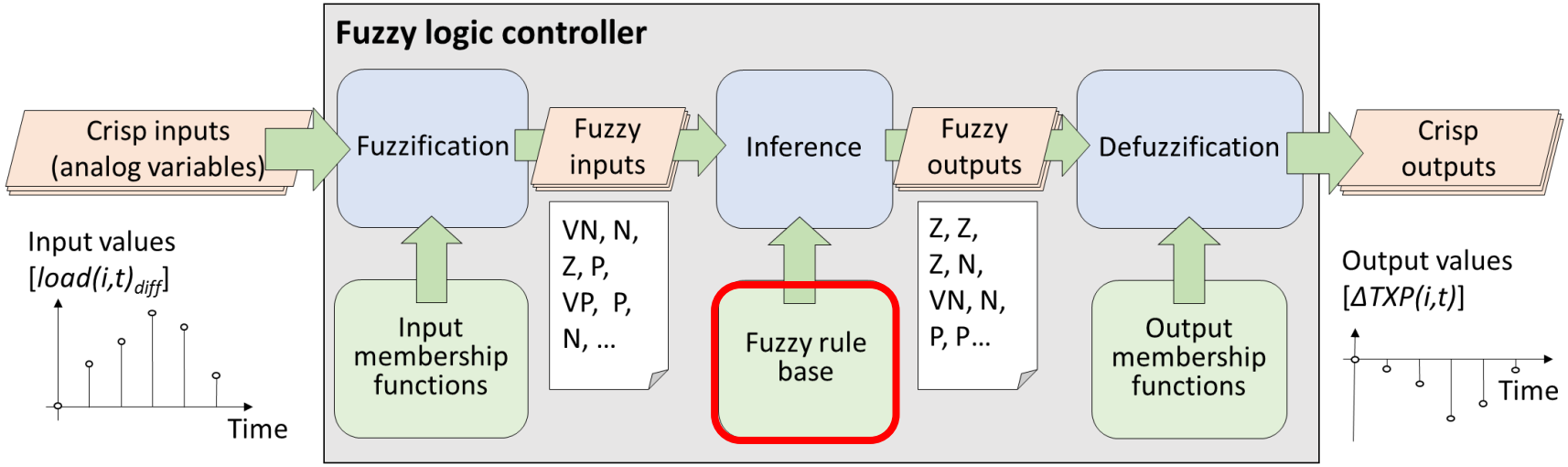


Evaluation - Fuzzy logic controller

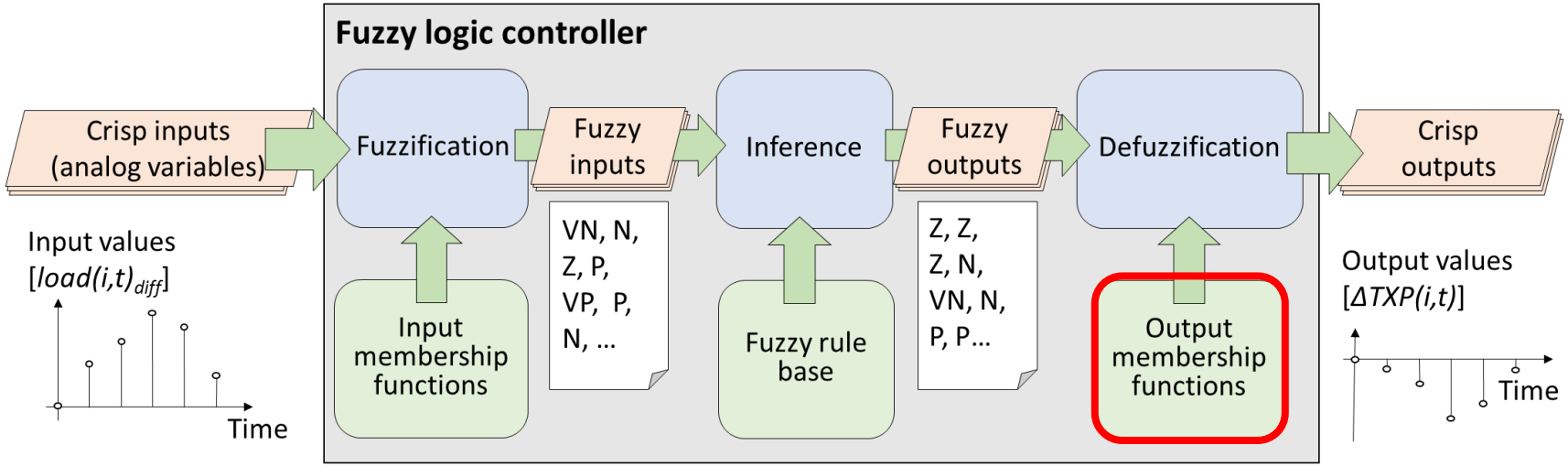
- **Fuzzy rule base**
  - Linguistic rules.

$load(cell_i, t)_{diff}$	Operator	$\Delta Ptx(cell_i, t)$	$\delta Ptx(cell_i, t+1)$
VN	AND	VN	VP
VN	AND	N	VP
VN	AND	Z	P
N	AND	VN	VP
N	AND	N	P
N	AND	Z	P
Z	AND	VN	VP
Z	AND	N	P
Z	AND	Z	Z
P	AND	-	N
VP	AND	-	VN

ARC

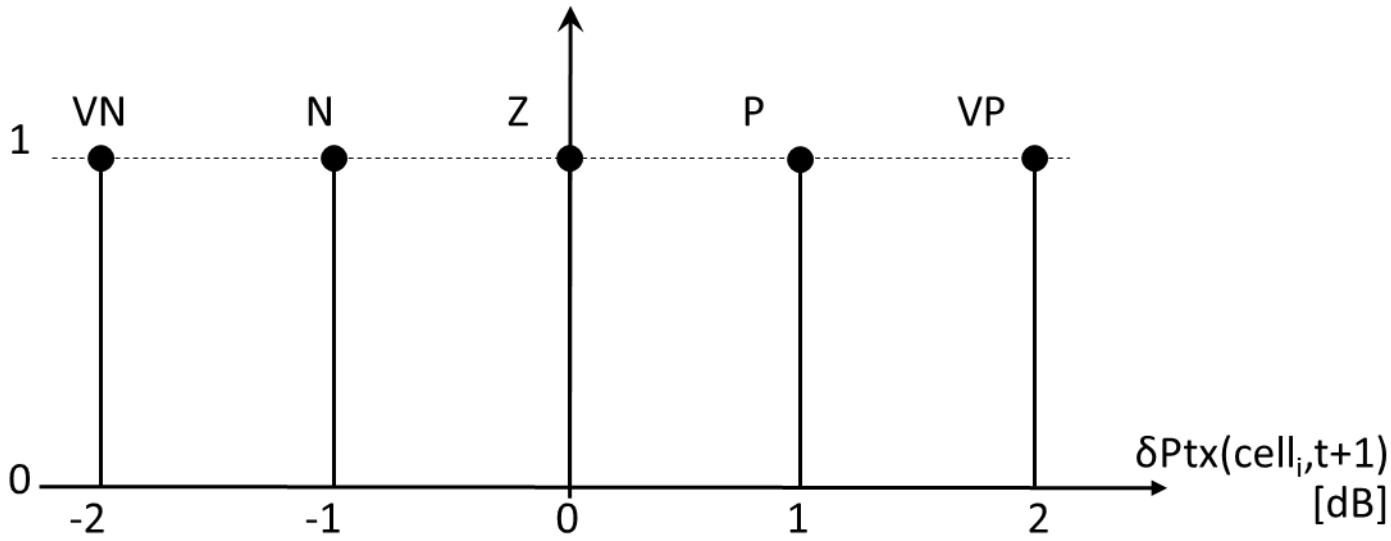
Evaluation - Fuzzy logic controller

- **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

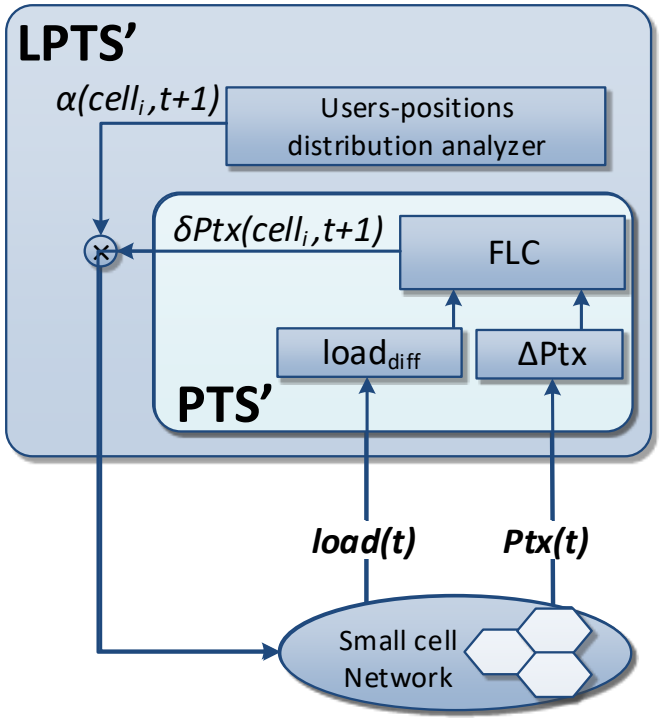
- **Output membership functions**
  - Converts fuzzy values of transmitted power change to numerical values.
  - Reduced speed for each step due to the risk of oscillation.



ARC

Evaluation - LPTS'

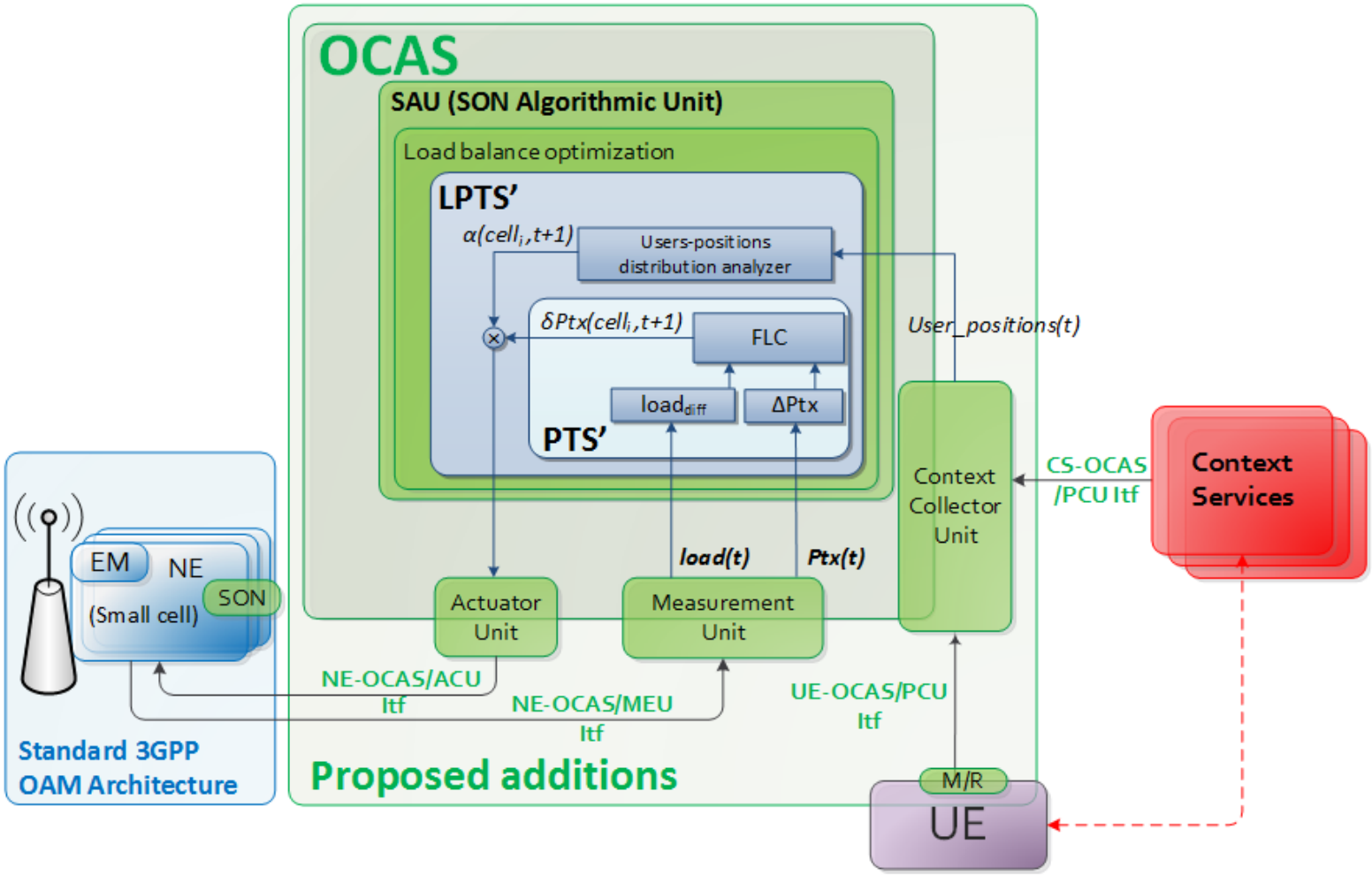
- Reduced variation in each algorithm epoch due to the risk of oscillation and overshooting.
- **LPTS' – location-aware PTS'**
  - User positions as a new input.
  - What if we could increase the speed of the process knowing the users positions?
  - Accelerator parameter → simple initial step: concentration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



ARC

Evaluation - Scheme

- **Implementation in the OCAS architecture.**

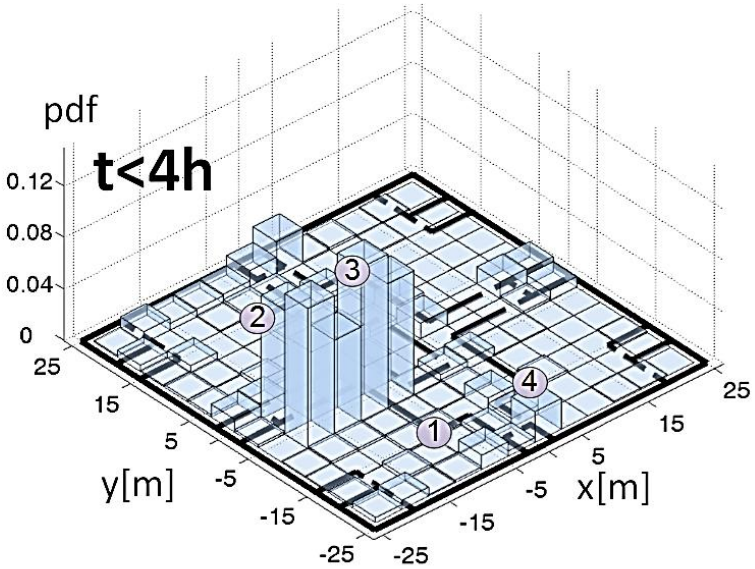


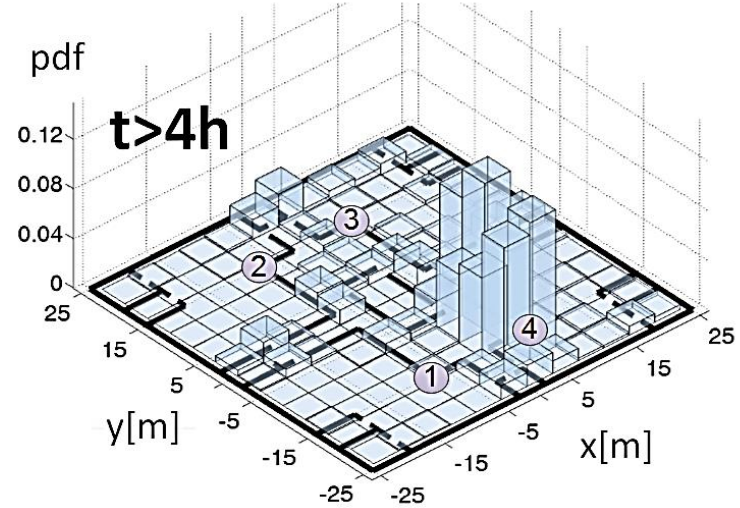
Evaluation - Analysis

- **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 a existing connection to stay in standby before it is finished.

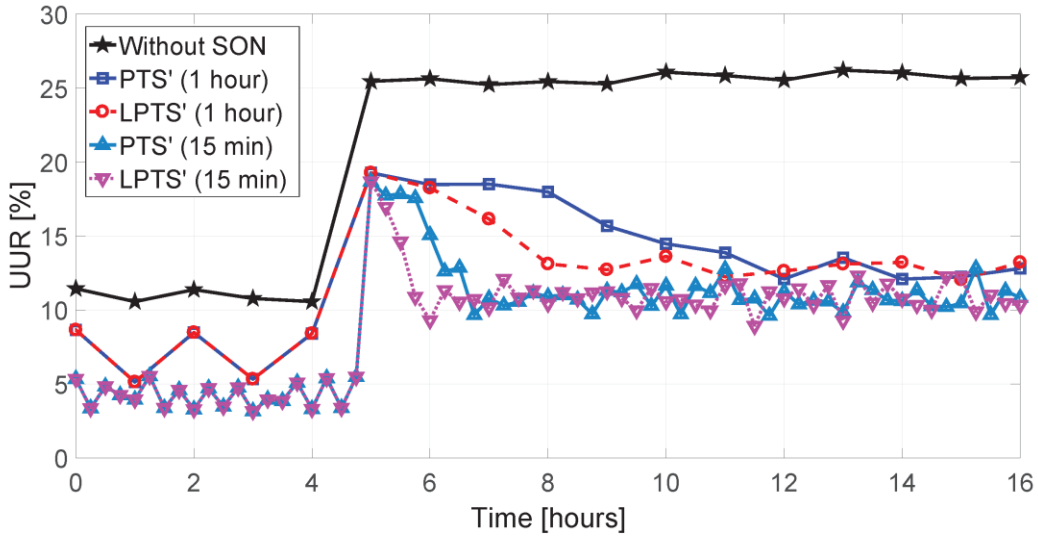




ARC

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 the based of more refined analysis of the cellular network of the user distributions: associated papers and thesis in self-optimization.

S. Fortes, A. Aguilar-García, R. Barco, F. Barba, J. Fernández-Luque, and A. Fernández-Durán, "Management architecture for location-aware self- organizing LTE/LTE-A small cell networks," IEEE Communications Magazine, IEEE, vol. 53, pp. 294–302, January 2015.

Index

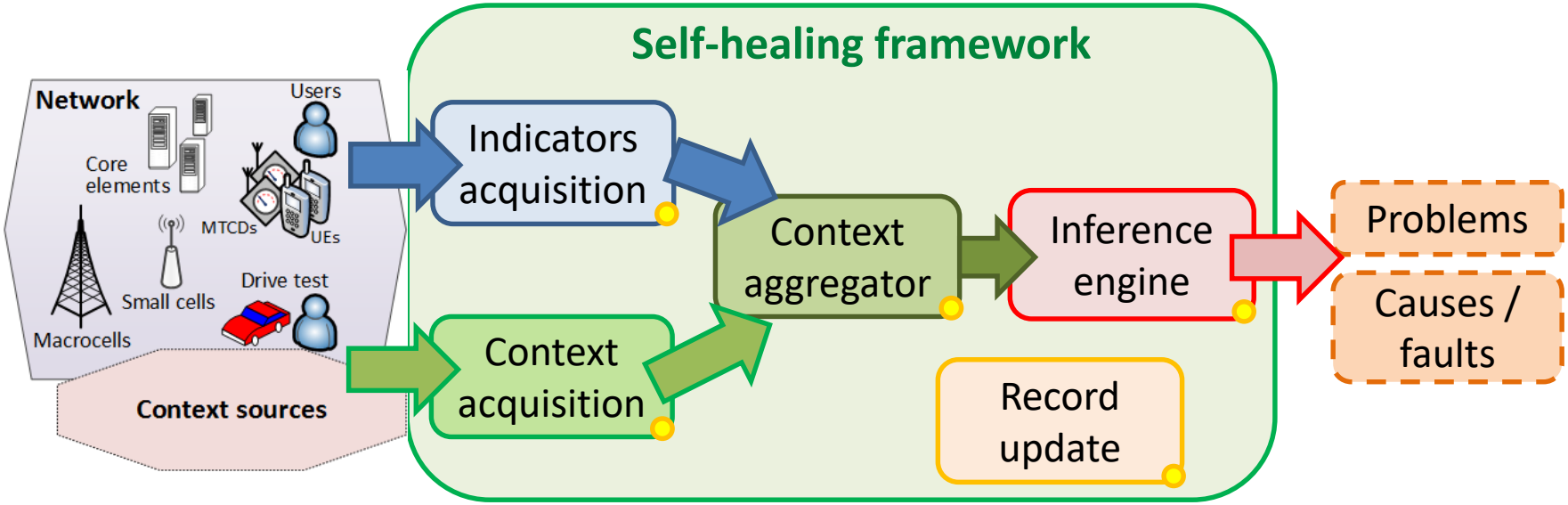
FRA

Motivation and framework elements

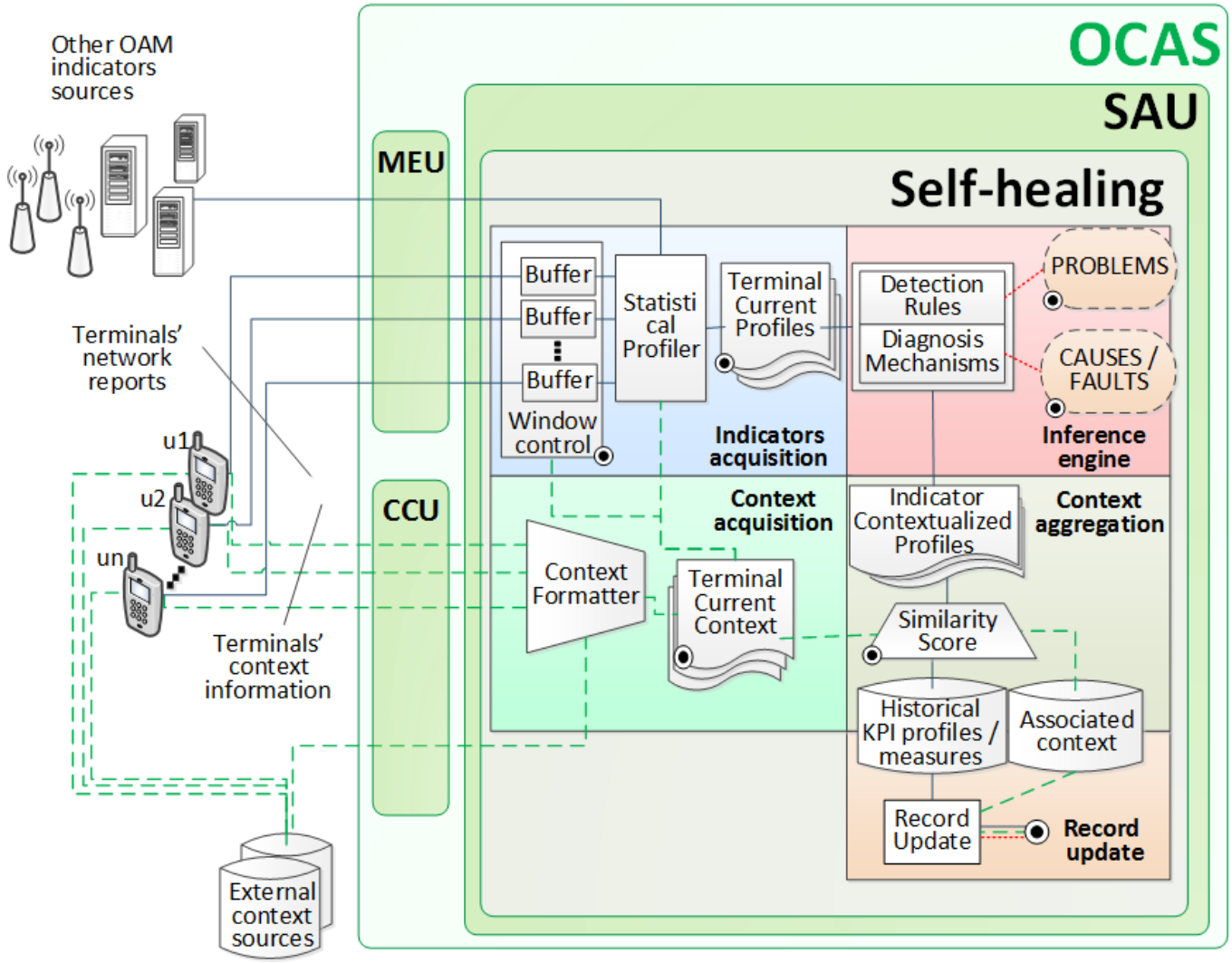
- **Goal:**
  - Providing a reference logic framework for the development of context-aware self-healing mechanisms.
  - UE focus.

FRA

- **Main elements**



Framework - UE-profiling based model



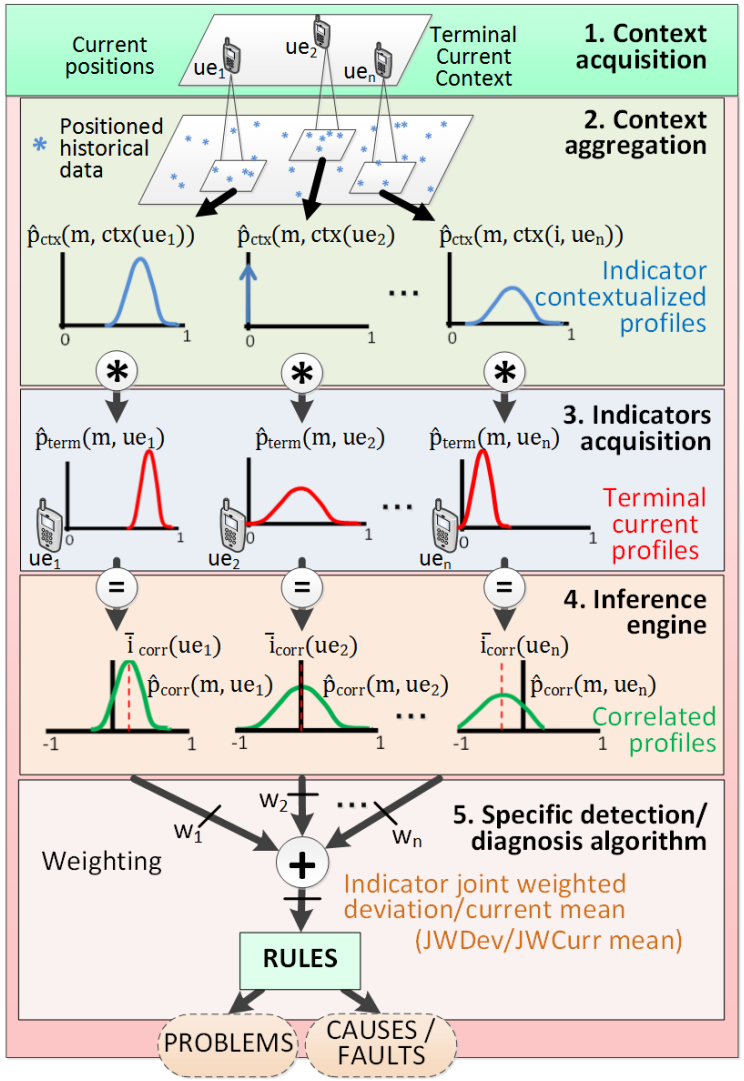
FRA

PoC: Cell outage detection

- **Mapped in the logical framework**
- **Statistical comparison between expected given context and current**
  - Indicator contextualized profiles

    $\hat{p}_{ctx}(m, \boxed{ctx(ue)})$
  - Terminal current profiles

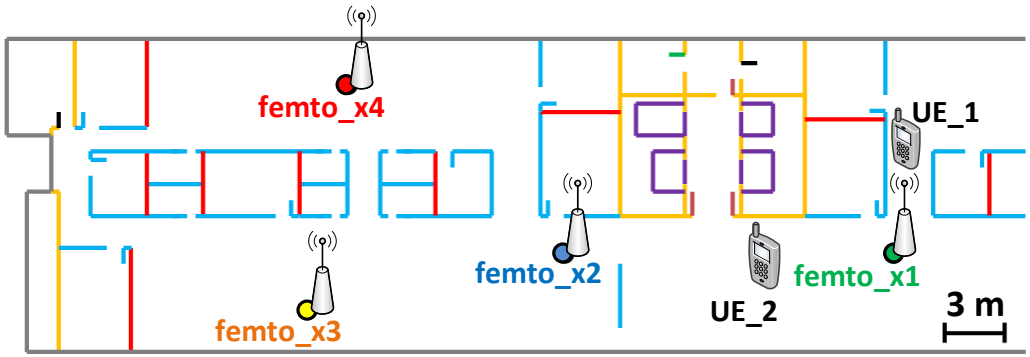
    $\hat{p}_{term}(m, \boxed{ue})$
  - Divergence
- **Multiple options**
  - *Profiles:* Means, histogram, Gaussian, beta…
  - *Divergence*: f-divergence (KL distance, Hellinger), pdfs cross-correlation…
- **Inference**
  - JWDev: Joint weighted deviation mean
  - Rules: thresholds.



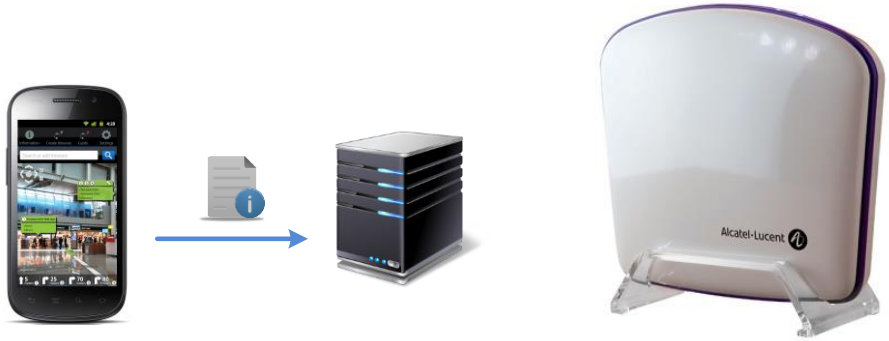
FRA

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.



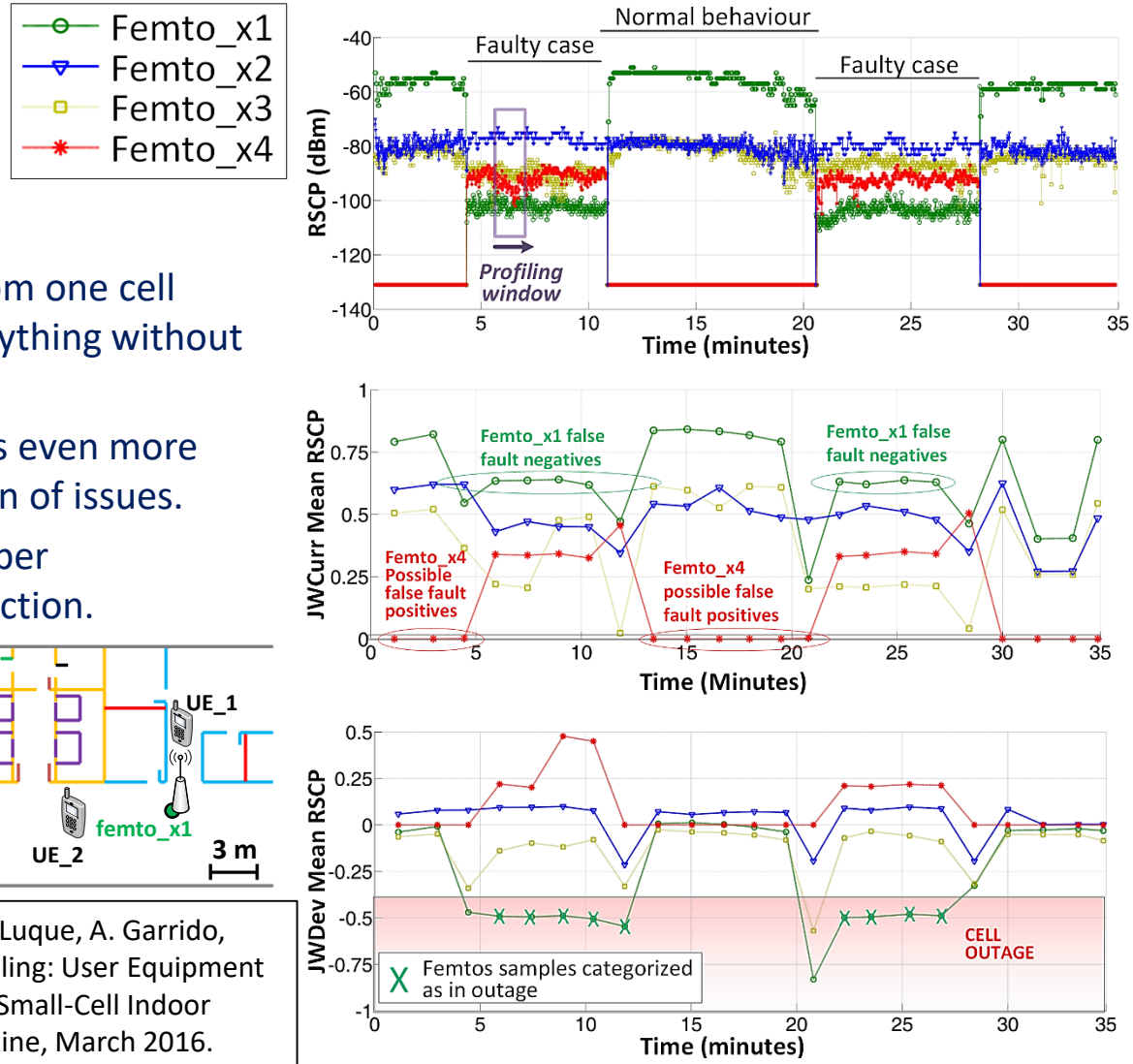
External Wall: Glass + Brick	Doors: Wood
Internal Wall: Glass	Doors: Glass
Internal Wall: Wood	Doors: Metal
Internal Wall: Brick	Doors: Metal + Wood
Internal Wall: Elevator	Doors: Elevator

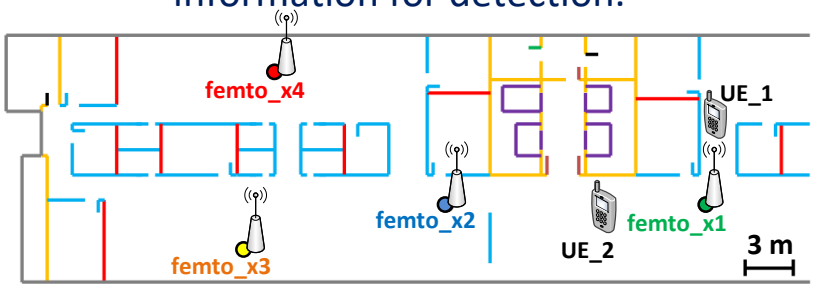


FRA

Test trial - Evaluation

- **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.



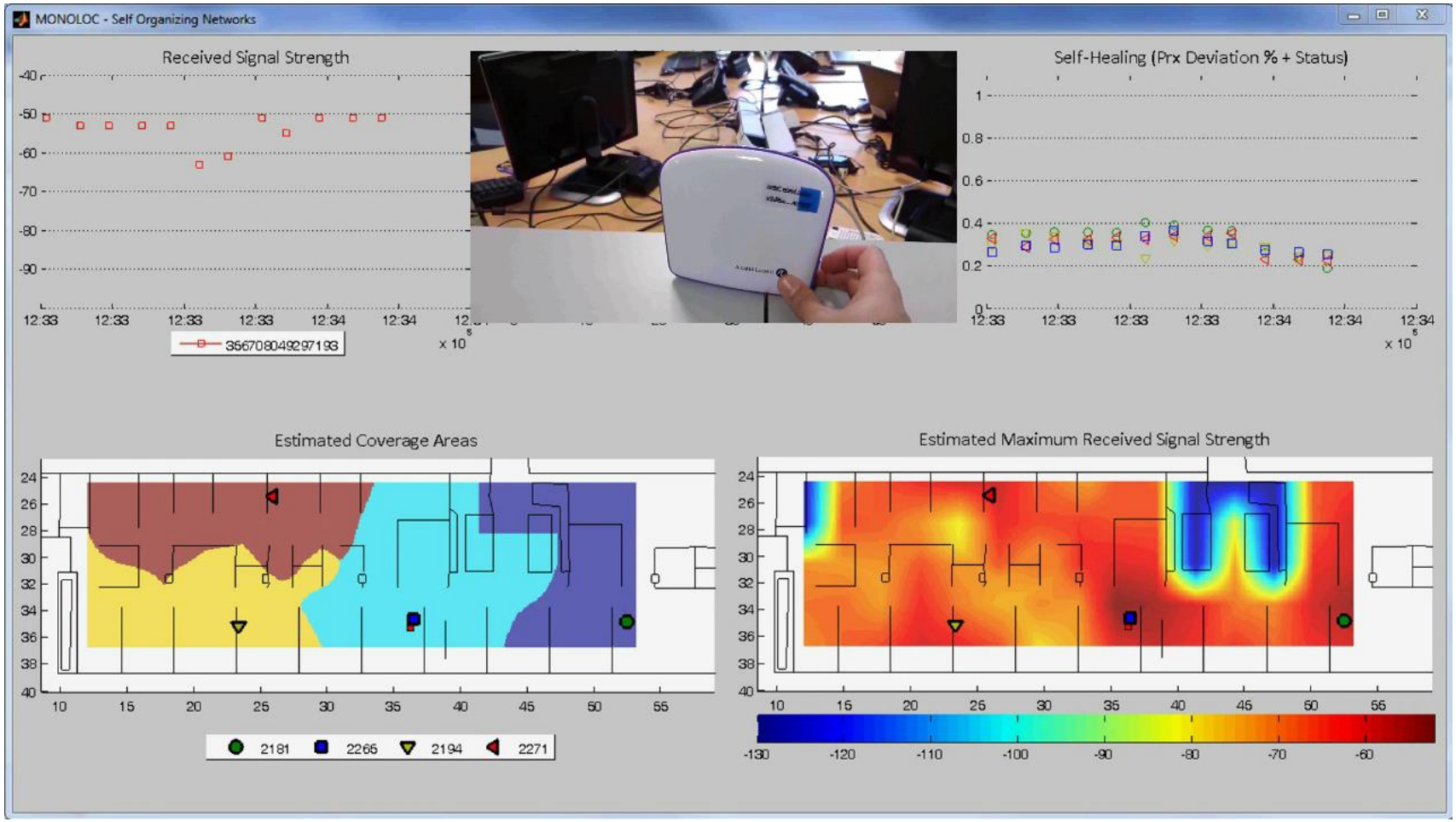


S. Fortes, A. A. Garcia, J. A. Fernandez-Luque, A. Garrido, and R. Barco, "Context-Aware Self-Healing: User Equipment as the Main Source of Information for Small-Cell Indoor Networks," IEEE Vehicular Tech. Magazine, March 2016.

FRA

Test trial - Real implementation

- A little demo.



FRA

Test trial - Real implementation

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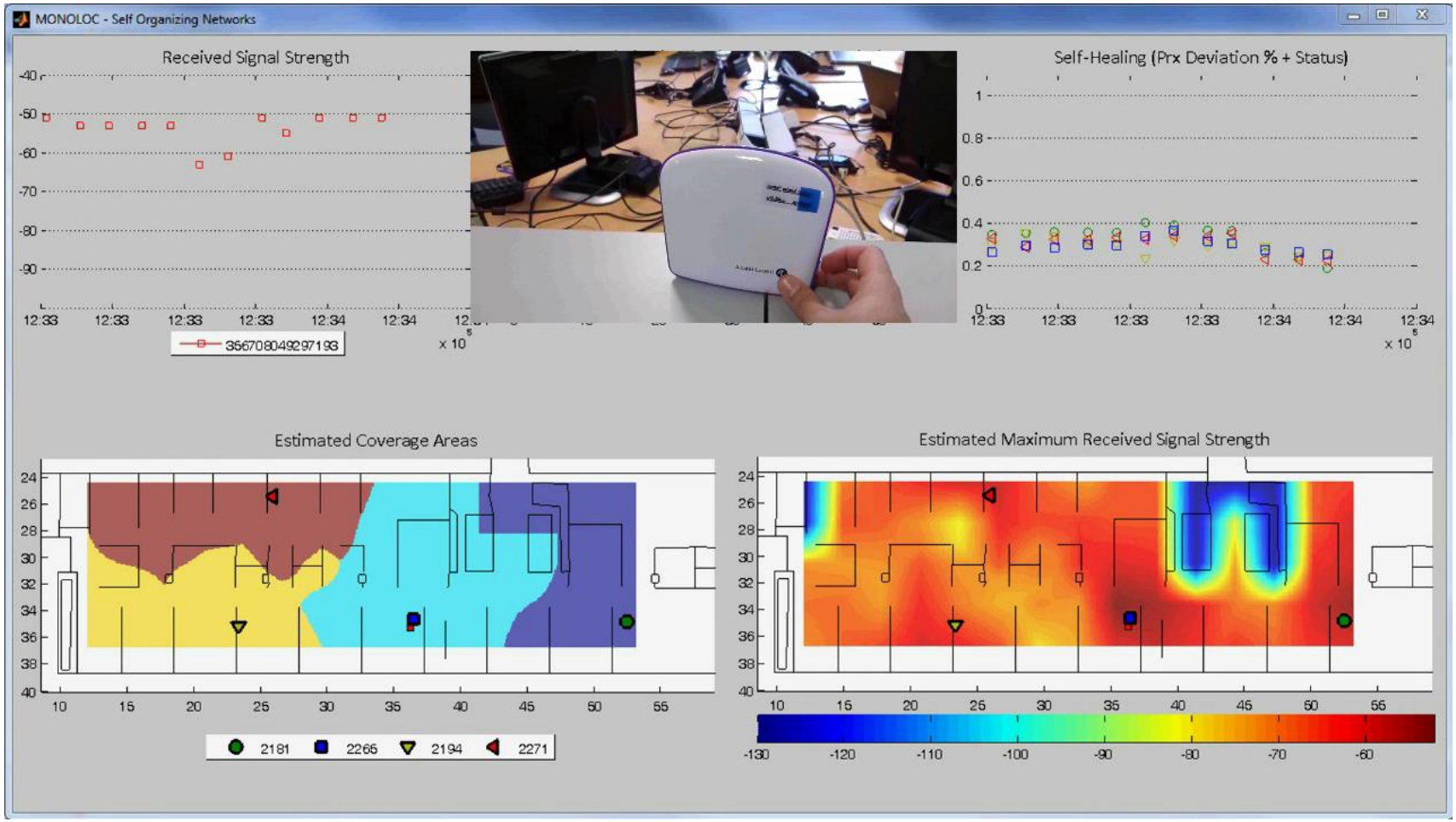
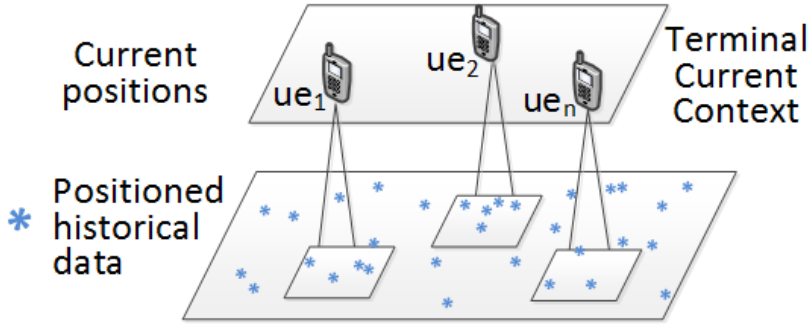


FRA

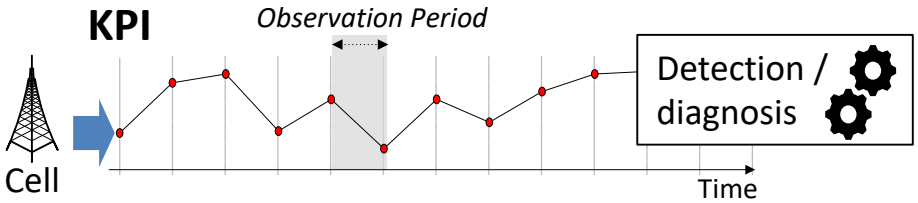
Index

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.**

IND

Contextualized indicators - Formulation

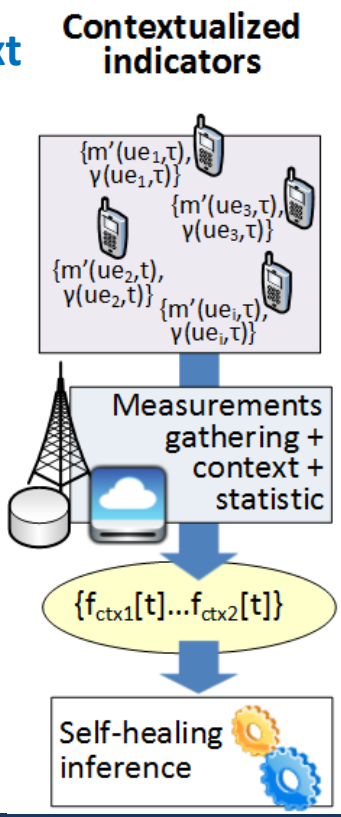
- $\gamma(ue,\tau)$, **the context of an** ue **for a certain instant** τ **can be described as a multidimensional vector.**

$$\gamma(ue,\tau) \sim \{\underbrace{x(ue,\tau), y(ue,\tau), z(ue,\tau)}_{\text{position}}, \underbrace{sc(ue,\tau)}_{\text{serving cell}}, \underbrace{\ldots}_{\text{other context}}\},$$

- **This is integrated in the contextualized indicator**

$$f_{ctx}[t] = \hat{\theta}(\{\underbrace{m'(ue,\tau)}_{\text{reported meas./evs.}}, \underbrace{\gamma(ue,\tau)}_{\text{context}} | \underbrace{\forall ue \in UE_{\mathbf{SC}}}_{\text{reporting UEs}}, \underbrace{\forall \tau \in t}_{\text{observation period}}\}),$$

- $\hat{\theta}$ **- any statistic, estimator or algorithm.**

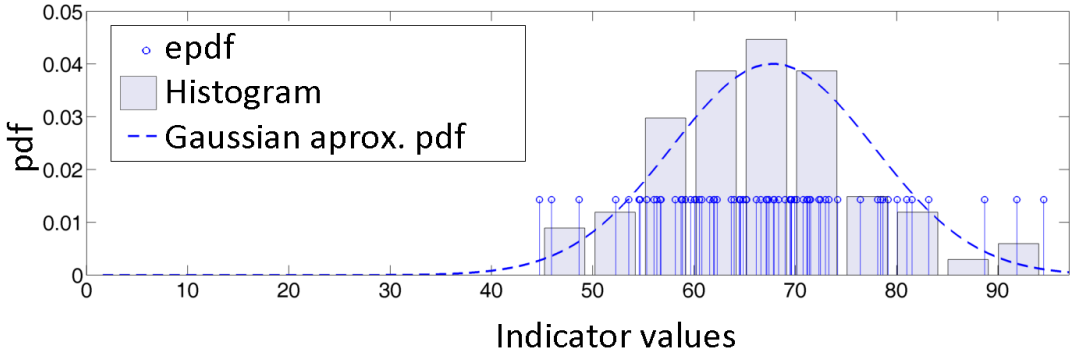


IND

Contextualized indicators - Sample weights

- **Objectives:** change relevance, select groups, specific filtering…for any statistic → **<u>sample weights</u>**
  - Social polling: vary the relevance of each sample.
  - Empirical pdf → histogram → distr. fitting → statistics.

$$epdf_{ctx}(m)\Big|_{M'} = \frac{1}{E_w} \sum_{\forall m' \in M'} \delta(m - m'(ue,\tau)) \cdot \underbrace{w(\gamma(ue,\tau))}_{\text{total weight given context}},$$



  - Also direct weighted statistics calculation.

IND

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

$$\boldsymbol{w}_T(\gamma(ue,\tau)) = \phi(\{w_{loc}(\gamma_{xyz}(ue,\tau)), w_{sc}(\gamma_{sc}(ue,\tau))...\}),$$

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

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

  - 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 ...

IND

- **Discussion:**
  - Classifier to obtain the probability of a certain network fault/case given a certain set of evidence (indicators)?

?

Context-aware diag. - Naive Bayes classifier

- **Once indicators are generated → input for any diagnosis mechanism**
- **Naive Bayes classifier:**

$$\widehat{p}(C = c_s | \boldsymbol{F} = \boldsymbol{f}[t]) = \frac{\widehat{p}(C = c_s) \prod_{\forall F \in \boldsymbol{F}} \widehat{p}(F = f[t] | c_s)}{\widehat{p}(\boldsymbol{F} = \boldsymbol{f}[t])}$$

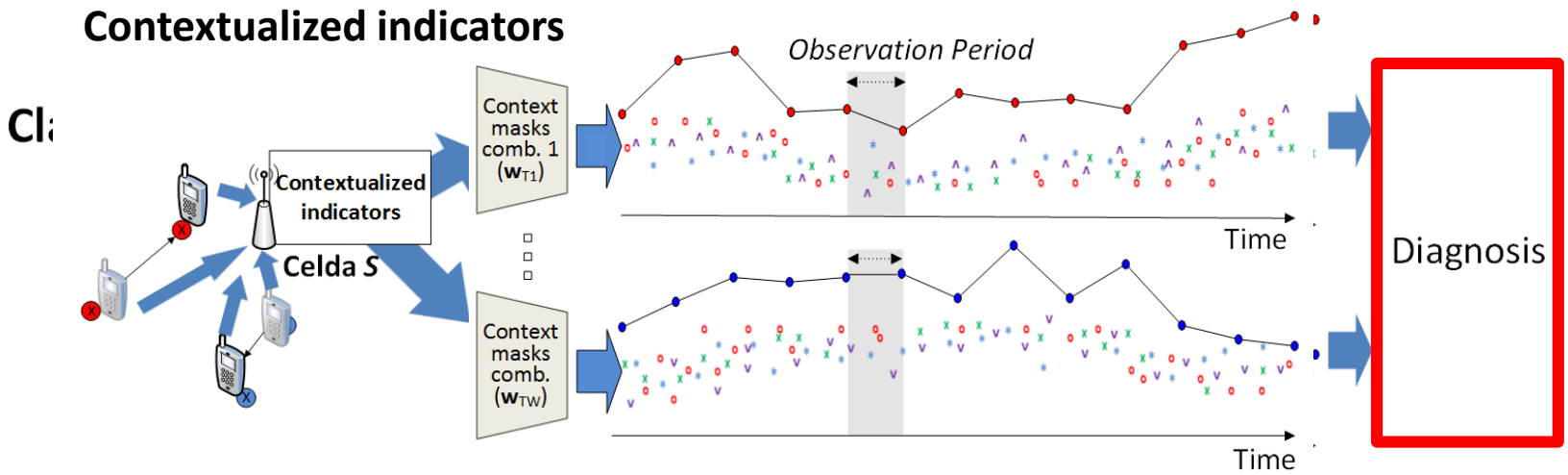
  - Set of input indicators $\boldsymbol{F} = \{F_{cls1}, F_{cls12}, ..., F_{ctx1}, F_{ctx2}, \ldots\}$
  - Evidence $\boldsymbol{f}[t] = \{f_{cls1}[t] ... f_{ctx1}[t], \ldots\}$
  - $F_{ctx} = f_{ctx}[t]$ value in the observation period 't' for a particular contextualized indicator generated by a set of weight mask 'ctx'.
  - Conditional probabilities $\widehat{p}(F_{ctx} = f_{ctx}[t] | c_s)$ 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.

IND

Context-aware diag. - Concept

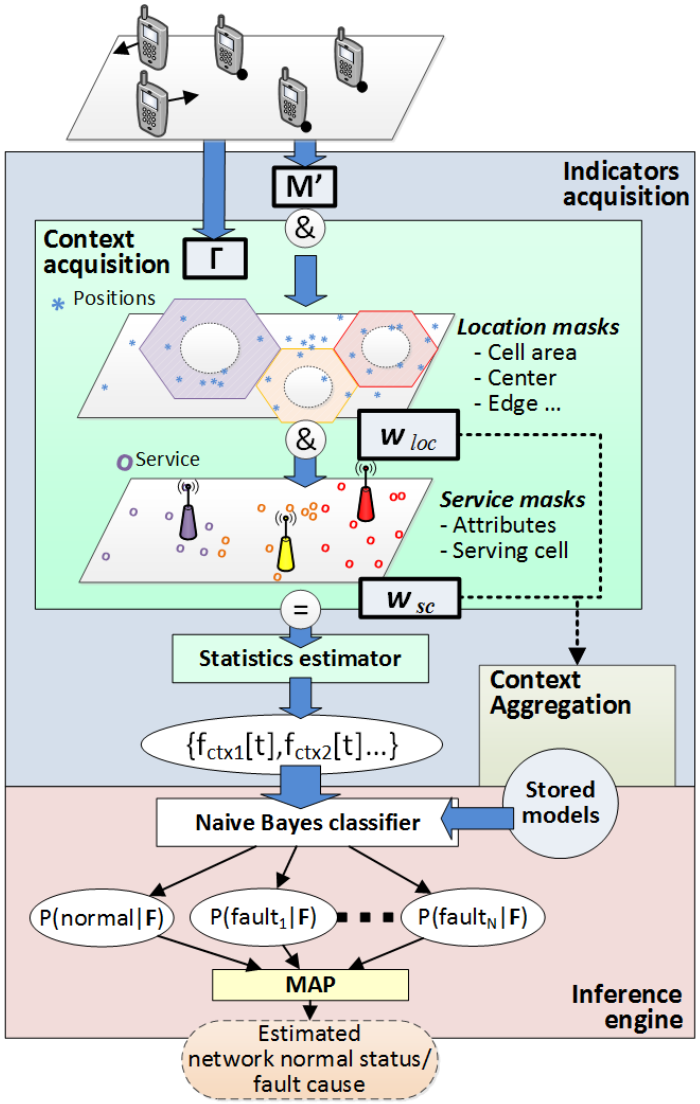
- Combine network measurements and UE context.
- Different weights → different indicators.
- Applicability → select the weights depending on the failure to diagnose.



IND

Context-aware diag. - Data and framework

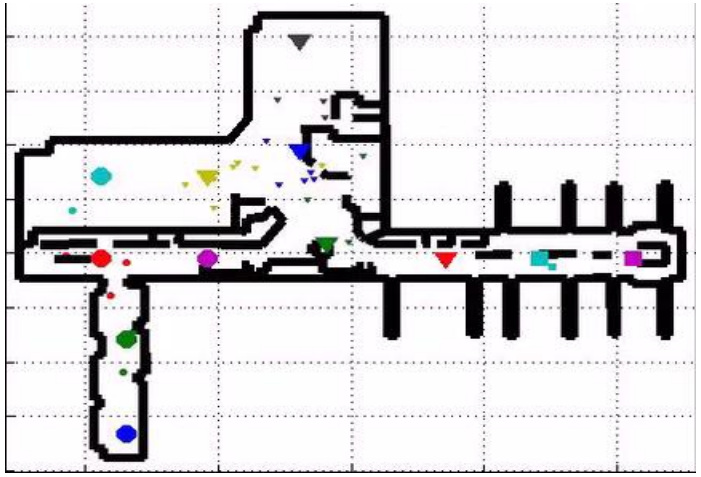
- **Framework implementation**
  - The need for buffers and historical data for individual UEs is avoided.
  - Statistics estimator for the generation of the indicators.
  - Naïve Bayes classifier is used for the diagnosis of the network status/fault.
- **Data scarcity**
  - Binary weighting process 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.

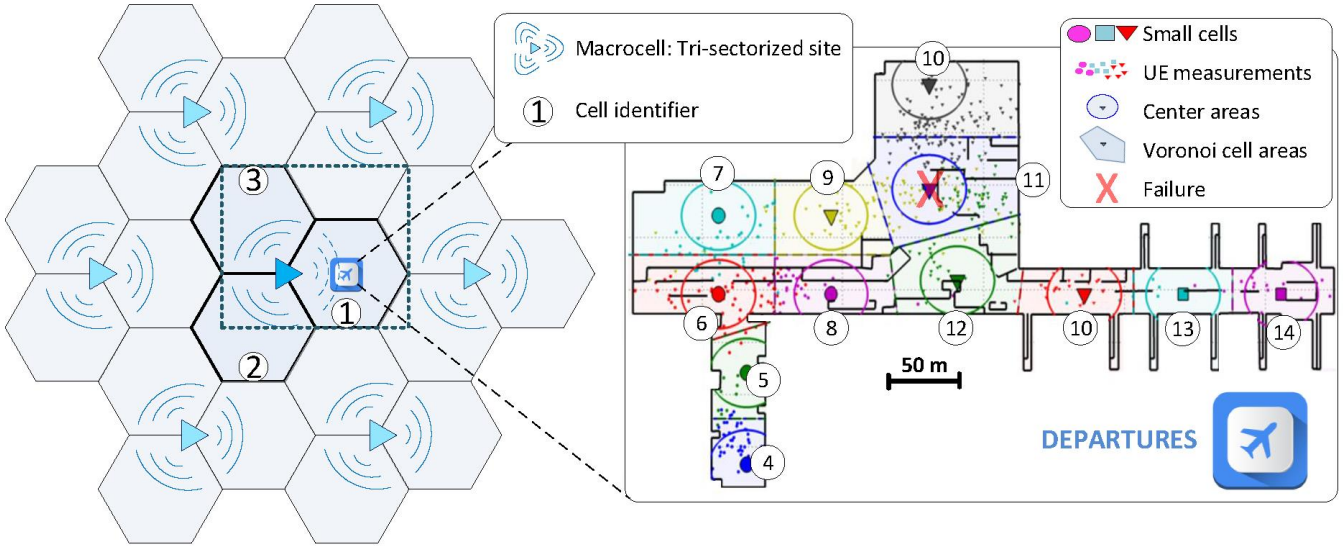


IND

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.

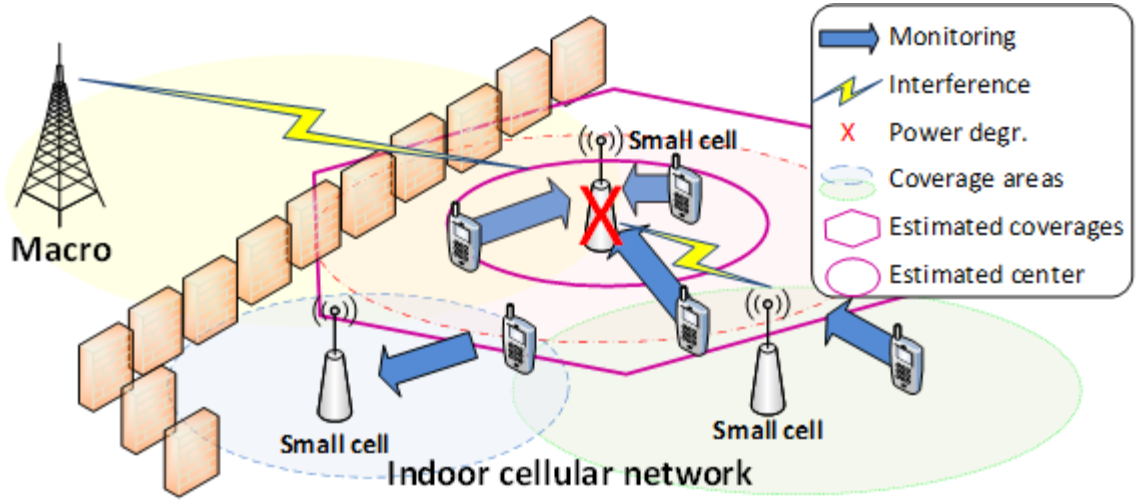




IND

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.
  - Center: radius. Edge: Coverage – center.
- **Indicator selection**
  - Interference → CQI-based (SINR).

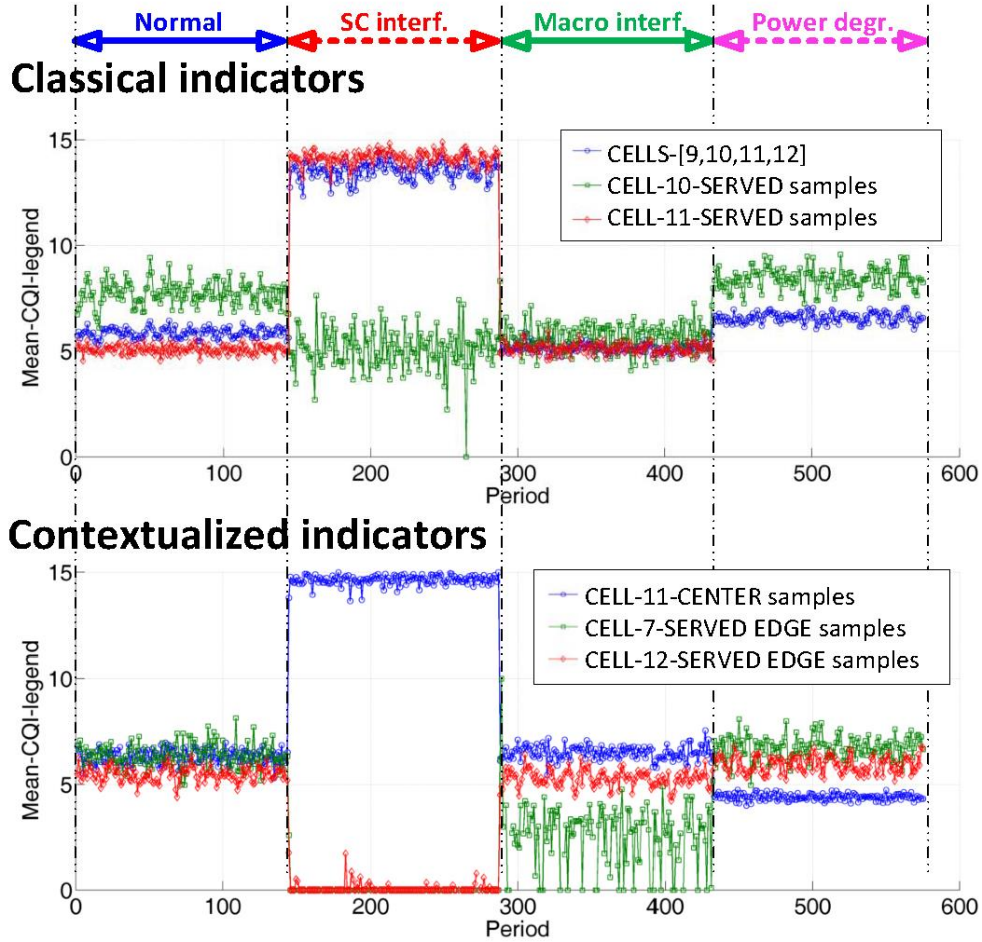


IND

Failure	Classic cell indicator	Contextualized indicator
Small cell interference	Interfered cell	Interfered cell EDGE and served by it
Macro interference	Small cell close to macro and building perimeter	Small cell close to macro and building perimeter EDGE and served by it
Power degradation	Served by adjacent	Degraded cell CENTER

Evaluation – Indicators (time distribution)

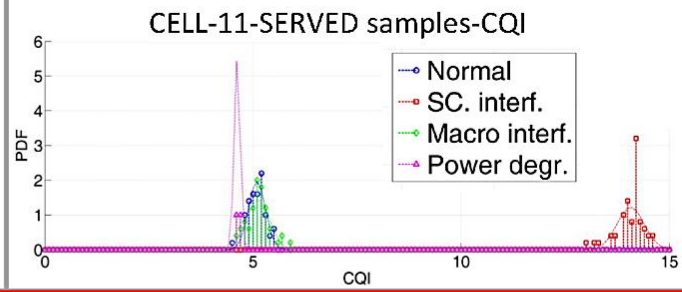
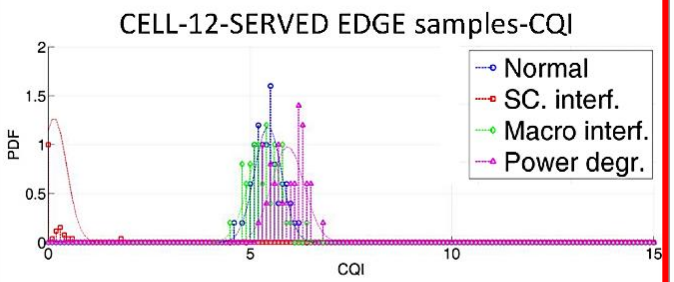
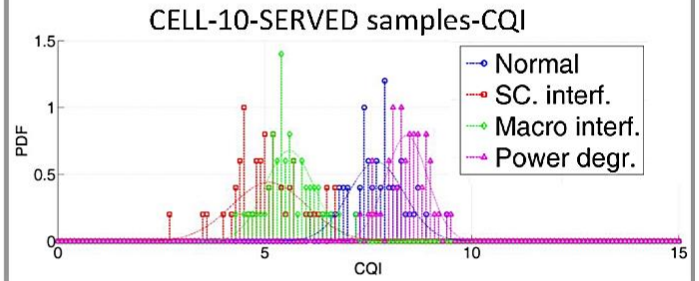
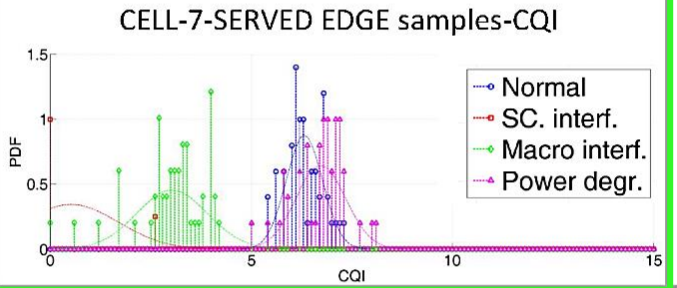
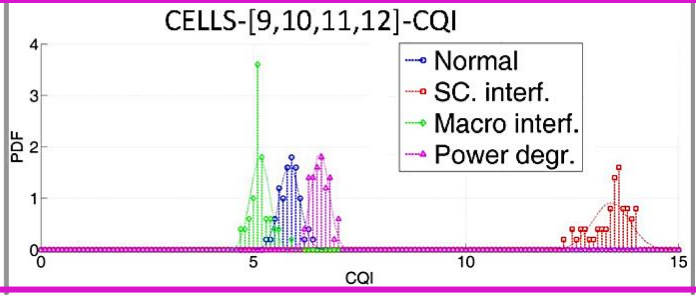
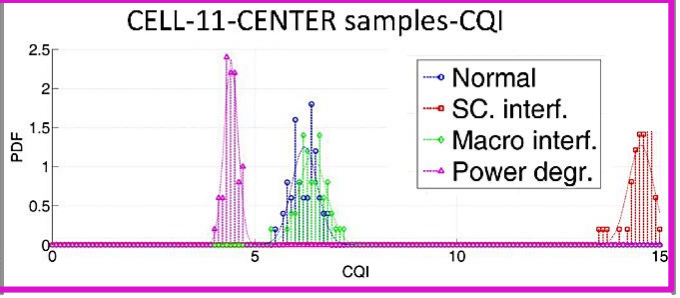
- **Comparison between classic and contextualized indicators → Cell 11 case.**



IND

Evaluation – Indicators

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

Main identifiable fault	Classic Indicators	Contextualized Indicators
Small cell interf.		
Macro interf.		
Power degr.		

IND

- **Discussion:**
  - How to measure the quality of a diagnosis system?

?

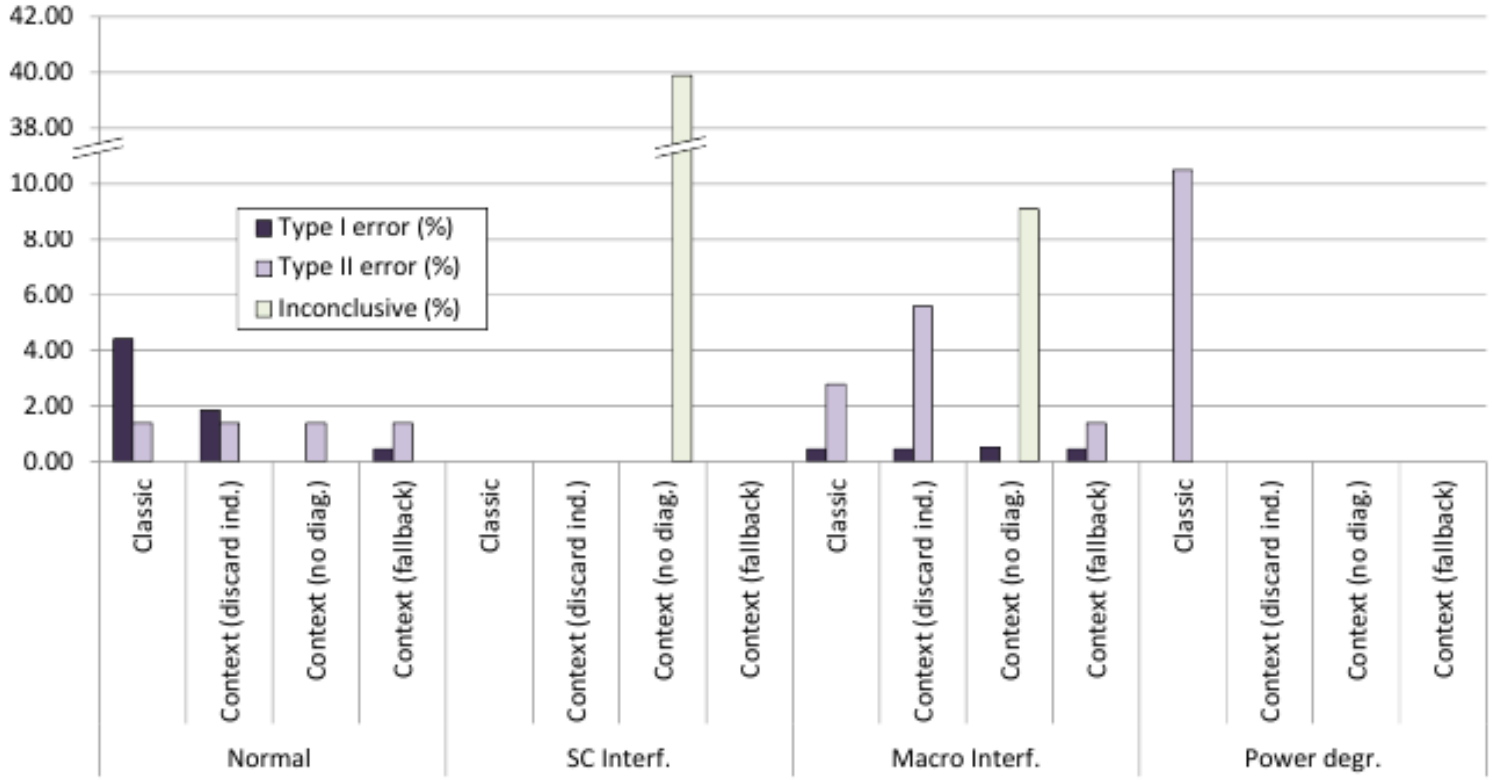
Evaluation - Results

- **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.

IND

Evaluation - Results

- **Comparative between classic and contextualized-based approaches**
  - Cell 11.

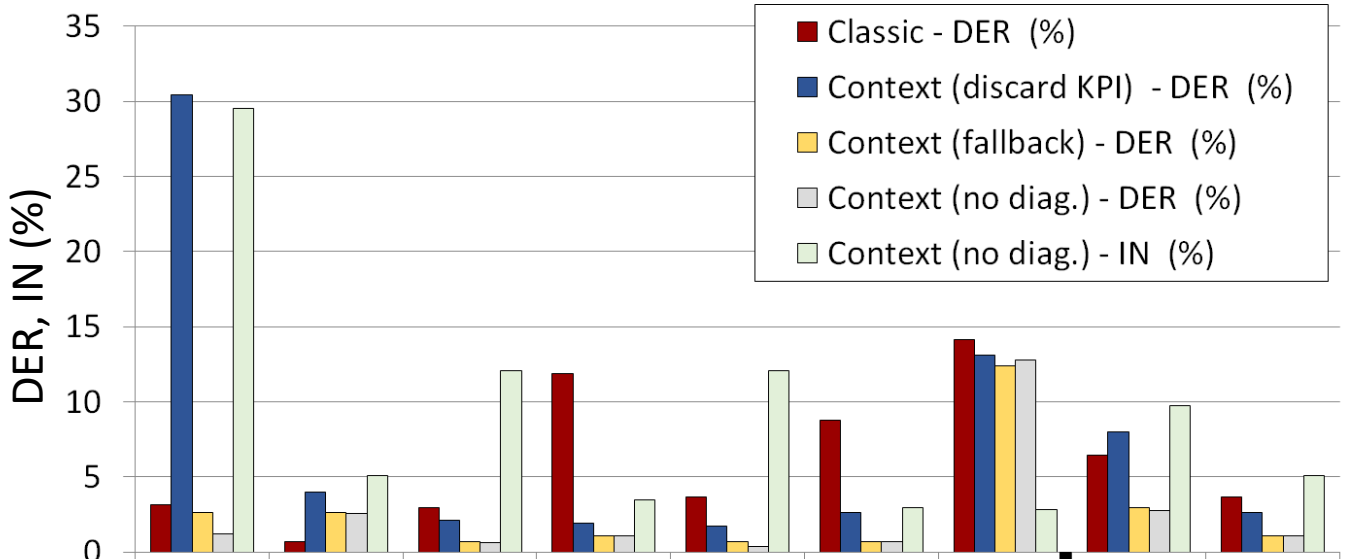


IND

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.

S. Fortes, R. Barco, A. Aguilar-García, and P. Muñoz, "Contextualized indicators for online failure diagnosis in cellular networks," *Computer Networks*, vol. 82, pp. 96 – 113, April 2015.



	Cell 7	Cell 8	Cell 9	Cell 10	Cell 11	Cell 12	Cell 13	Average	Median
Classic - DER (%)	3.15	0.70	2.97	11.89	3.67	8.74	14.16	6.47	3.67
Context (discard KPI) - DER (%)	30.42	4.02	2.10	1.92	1.75	2.62	13.11	7.99	2.62
Context (fallback) - DER (%)	2.62	2.62	0.70	1.05	0.70	0.70	12.41	2.97	1.05
Context (no diag.) - DER (%)	1.24	2.58	0.60	1.09	0.40	0.72	12.77	2.77	1.09
Context (no diag.) - IN (%)	29.55	5.07	12.06	3.50	12.06	2.97	2.80	9.72	5.07

IND

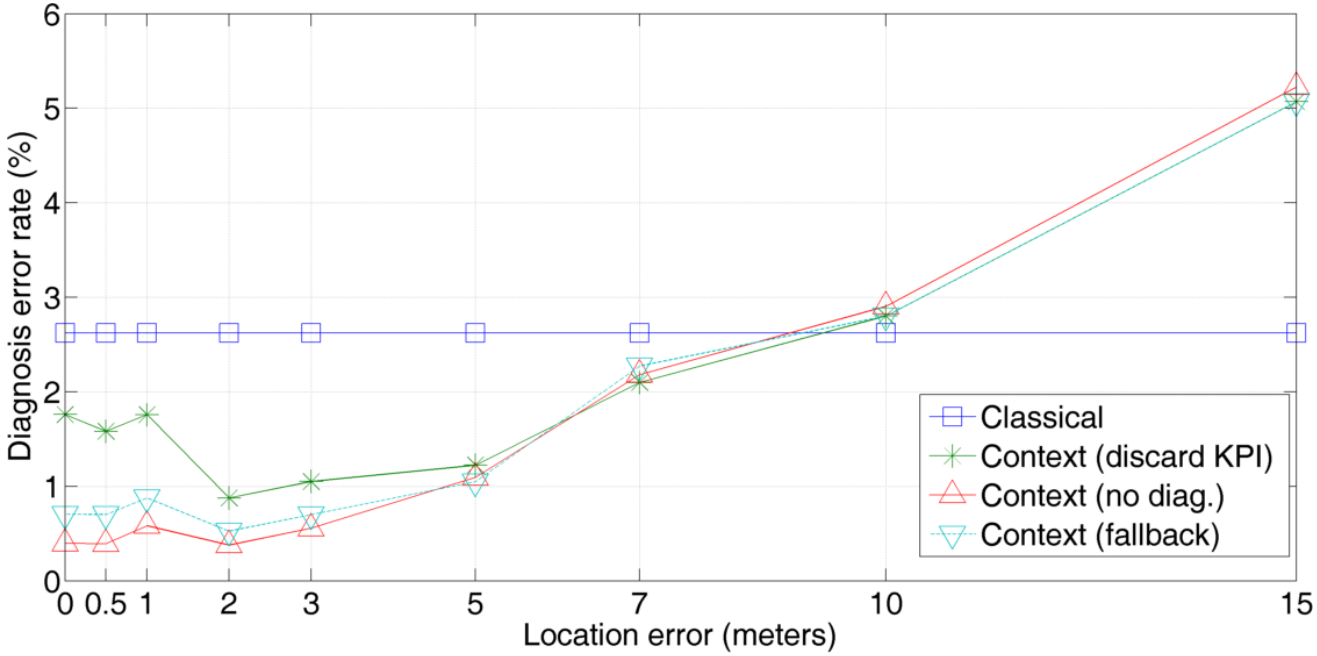
- **Discussion:**
  - Real positioning methods have inaccuracies. How to model them in our simulator?

?

Effects of localization inaccuracies

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

$$\begin{cases} e_x^m = N(\mu, \sigma) \\ e_y^m = N(\mu, \sigma) \end{cases}$$



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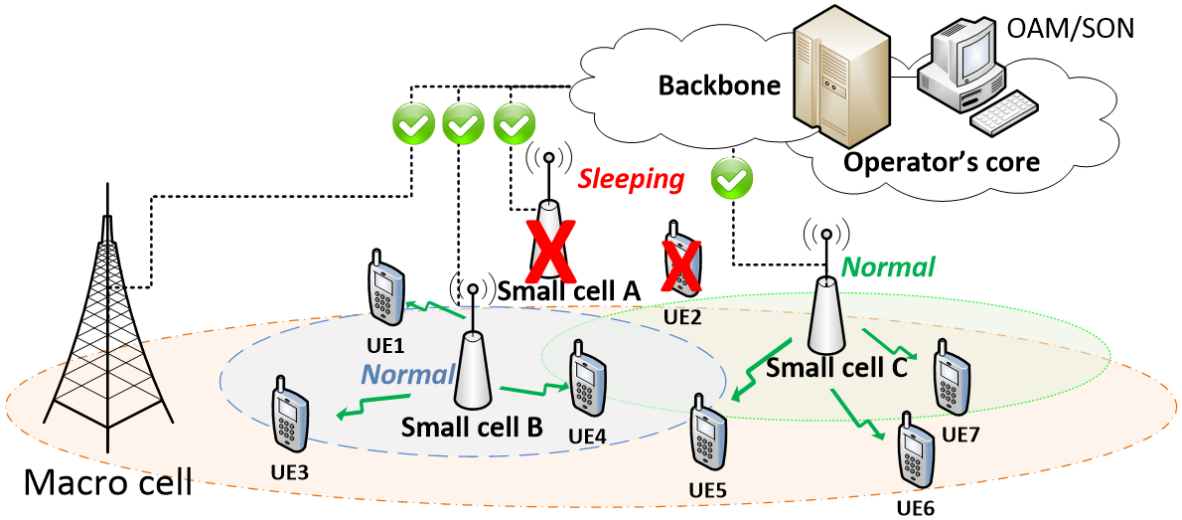
DST

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.



DST

- **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.**

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

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

  - Analysis of the approximation depending on available information

AOI calculation	Required information
Classic (no location / AOIs)	-
Test campaign	UE positions, positions during radiomap gathering
Site-specific detailed propagation	UE positions, BSs positions, transmitted power, obstacles, walls, propagation conditions
Simple log-distance path loss	UE positions, BSs positions, transmitted power

DST

Radio info application – AOIs (II)

- ***Areas of Interest* (AOIs)**
  - Log-distance path loss.

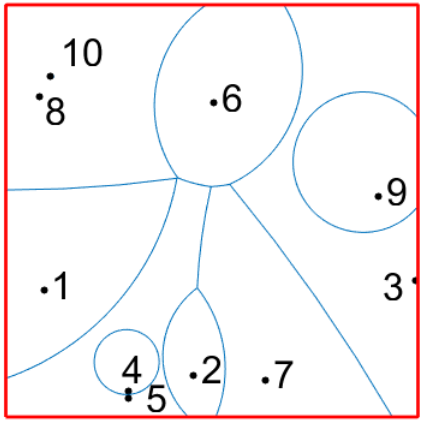
$$ECov(cell_i) = \left\{ (x,y) \in E^2 \middle| \frac{d((x,y,z),cell_i)}{P_{tx}^{1/\alpha}(cell_i))} < \frac{d((x,y,z),cell_j)}{P_{tx}^{1/\alpha}(cell_j)}, \forall i \neq j \right\}$$

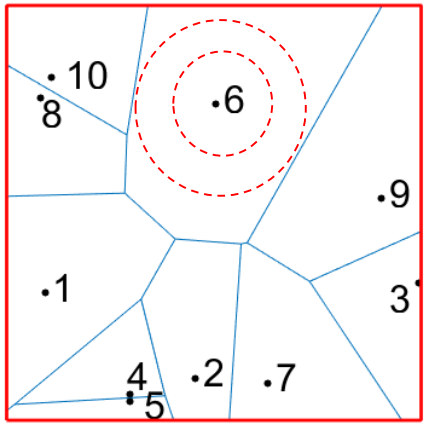
  - Multiplicatively Weighted-Voronoi tessellation → complex.
  - Circular center (and coverage if not equal transmission power).

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

$$R_{cent}(cell_i) = k_R * R_{cov}(cell_i)$$

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

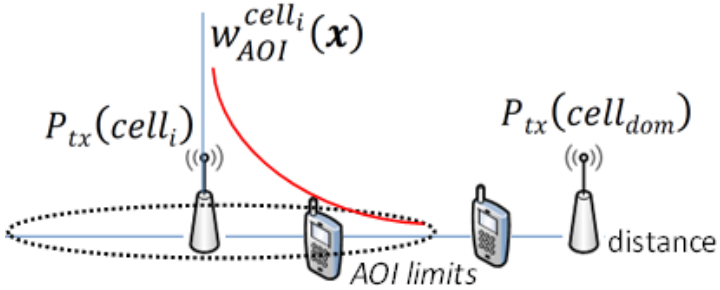




DST

Radio info application - Weights

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



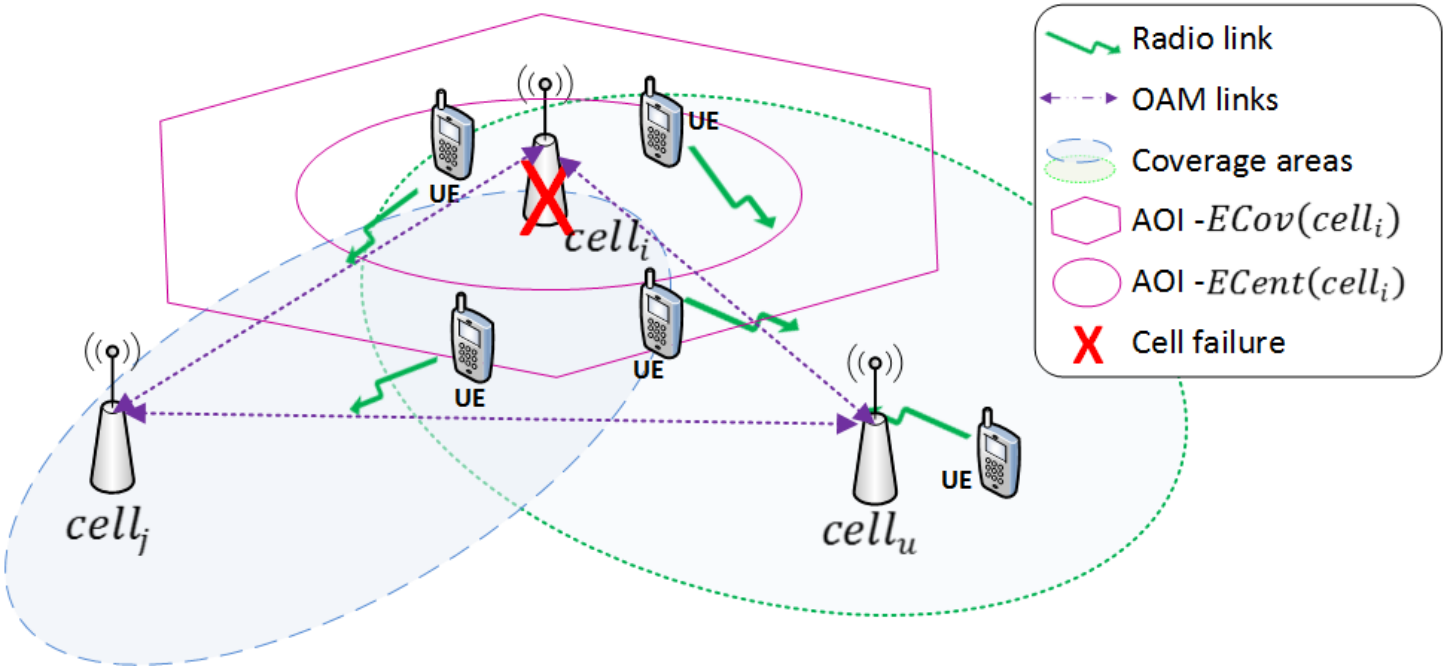
$$w_{AOI}^{cell_i}(x,y) = \begin{cases} \frac{P_{tx}(cell_i)/P_{tx}(cell_{dom})}{d((x,y),cell_i)/d((x,y),cell_{dom})^{\alpha}} & \text{if (x,y) inside AOI} \\ 0 & \text{otherwise} \end{cases},$$

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

DST

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 $\boldsymbol{cells}_i^{imp}$: the cell and its neighbors.



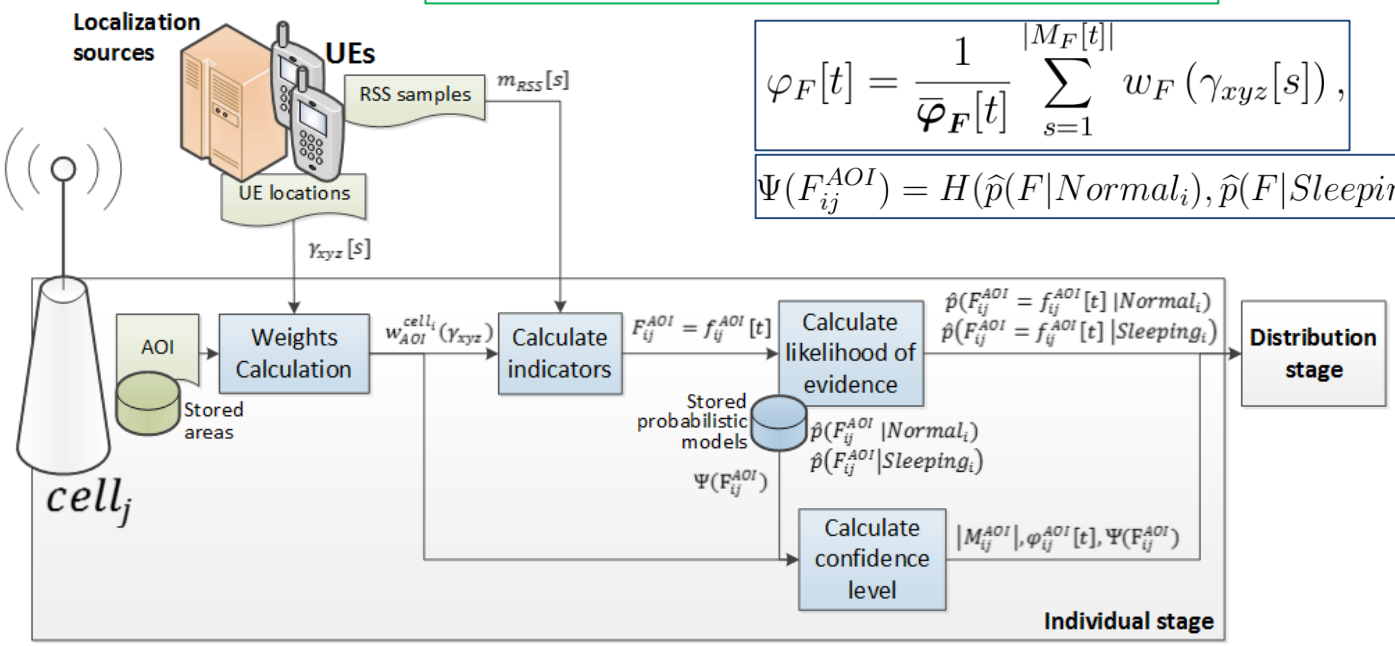
DST

Detection algorithm - Individual stage

- **Individual stage**
  - For each $cell_i$ (maybe faulty), each $cell_j \in \boldsymbol{cells_i^{imp}}$
  - compute the *metrics* F_{ij}^{AOI} associated with their served UEs in $cell_i$ AOIs,
  - their *conditional probabilities* $\widehat{p}(F_{ij}^{AOI} = f_{ij}^{AOI}[t]|Normal)$,
  - $\widehat{p}(F_{ij}^{AOI} = f_{ij}^{AOI}[t]|Sleeping)$
  - and *confidence level:* $\Omega_F[t] = (|M_F[t]| < |M|_{th}) * \varphi_F[t] * \Psi(F)$

$$\varphi_F[t] = \frac{1}{\overline{\boldsymbol{\varphi}}_{\boldsymbol{F}}[t]} \sum_{s=1}^{|M_F[t]|} w_F\left(\gamma_{xyz}[s]\right),$$

$$\Psi(F_{ij}^{AOI}) = H(\widehat{p}(F|Normal_i), \widehat{p}(F|Sleeping_i))$$



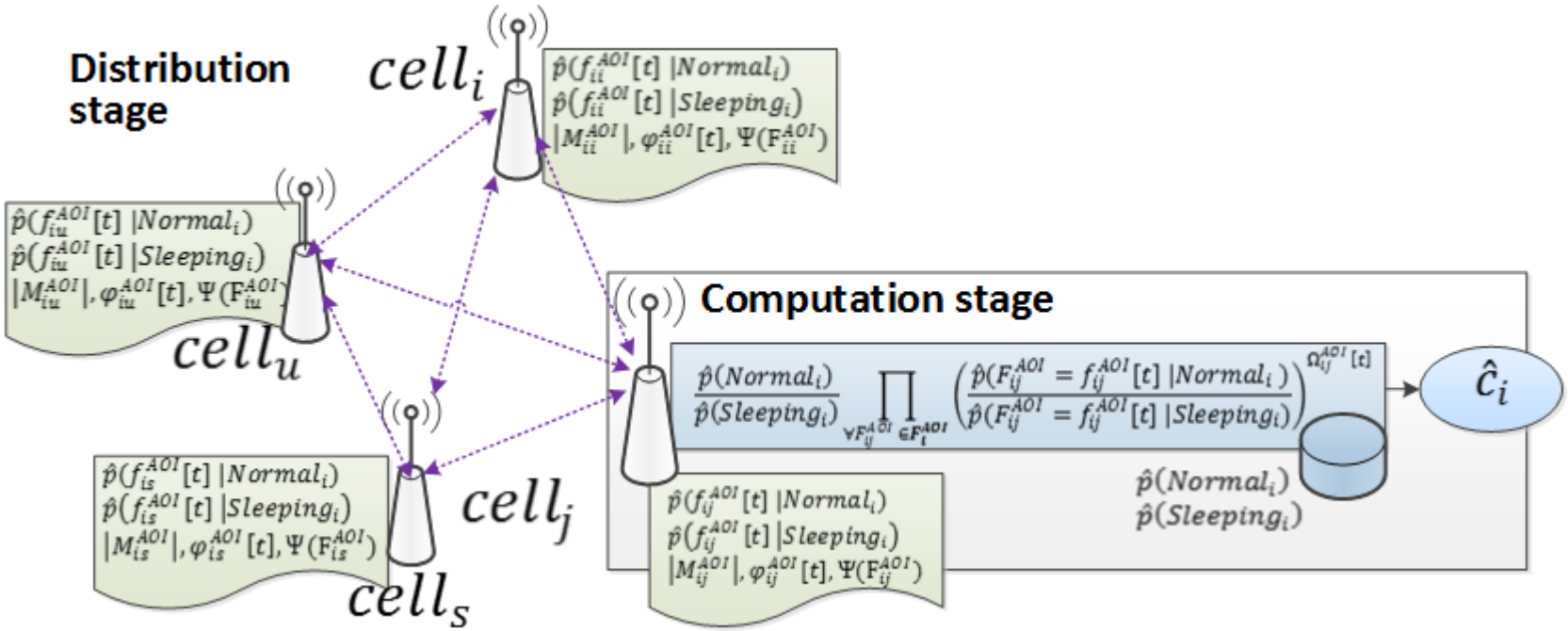
DST

Detection algorithm - Distribution stage

- Compute the posterior probability → detection

$$\frac{\widehat{p}(Normal_i)}{\widehat{p}(Sleeping_i)} \prod_{\forall F \in \boldsymbol{F}} \left(\frac{\widehat{p}(f[t]|Normal_i)}{\widehat{p}(f[t]|Sleeping_i)} \right)^{\Omega_F[t]} < 1 \rightarrow cell_i \text{ is faulty,}$$

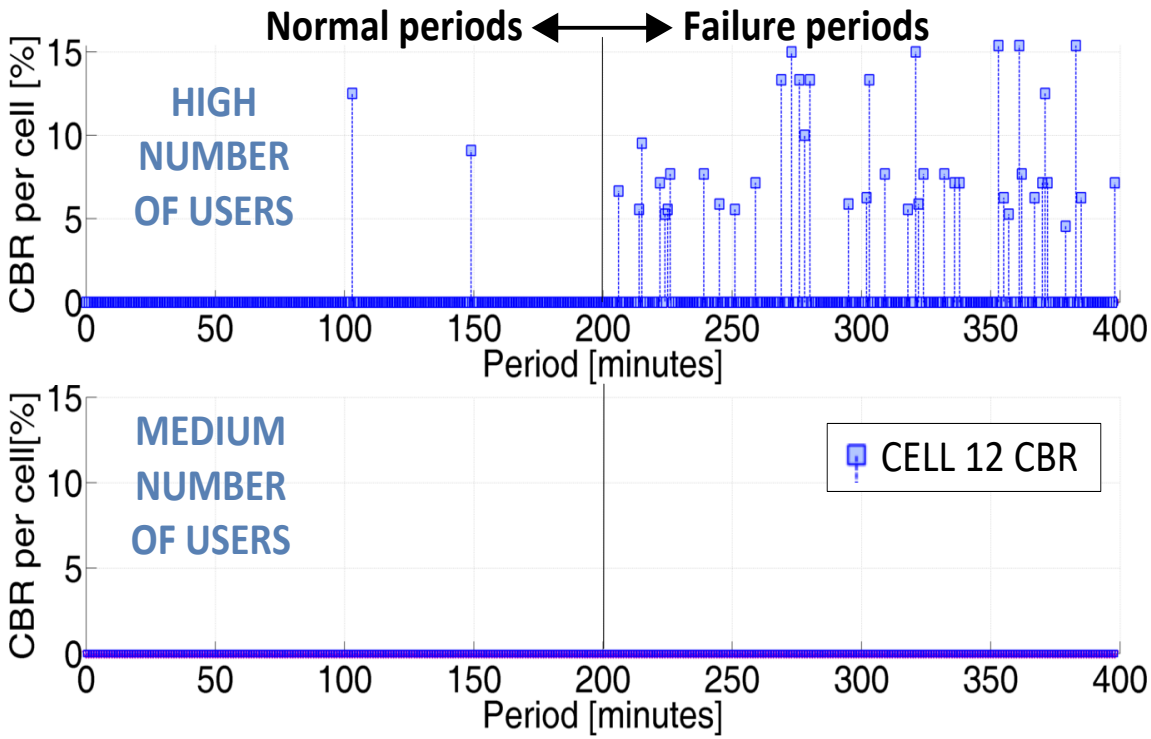
- After: consensus, alert to OAM, diagnosis, compensation, recovery…



DST

Evaluation - Set-up

- 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.



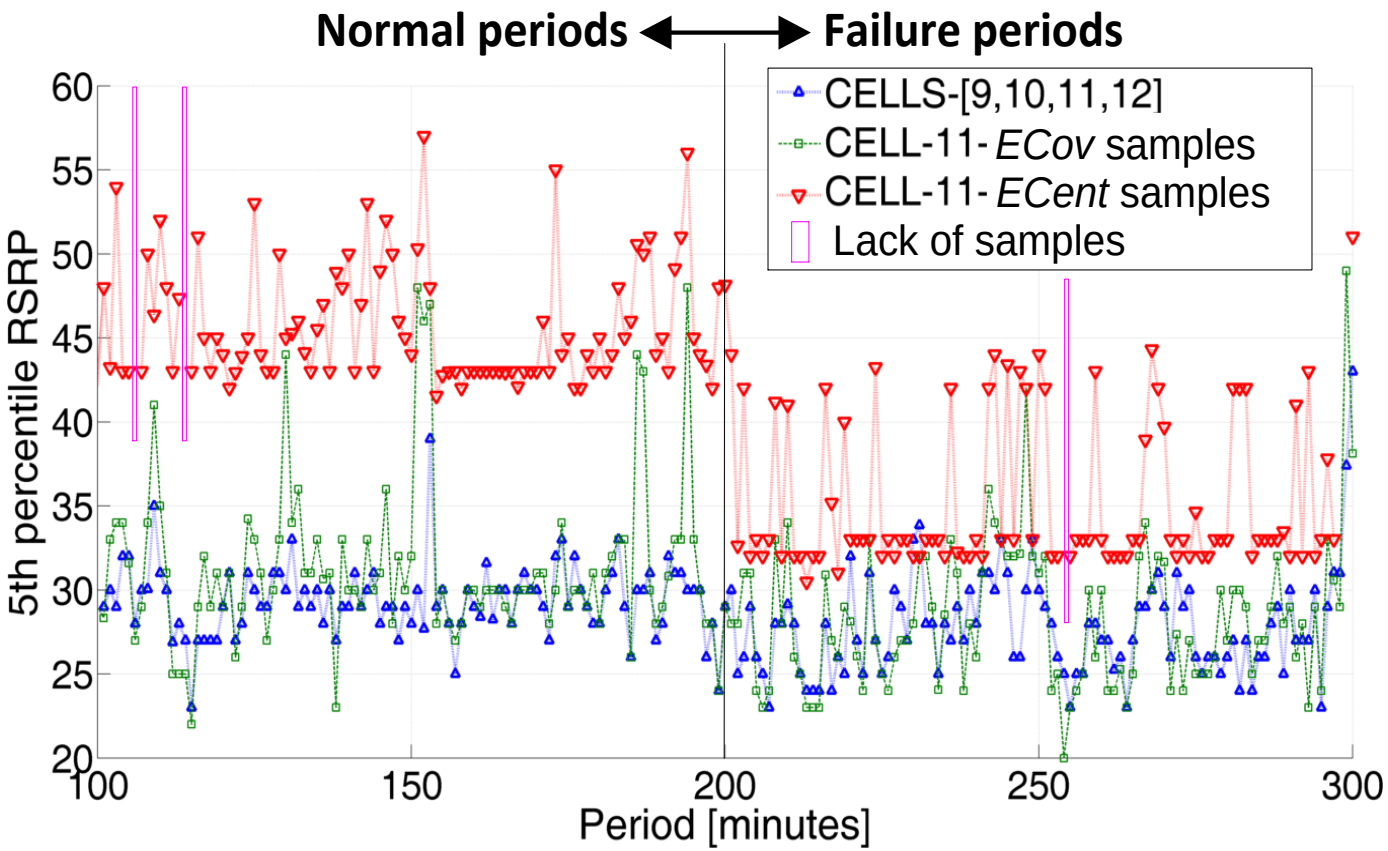
12 users/cell

7 users/cell

DST

Evaluation - Results

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



DST

- **Discussion:**
  - How to measure the quality of a detection system?

?

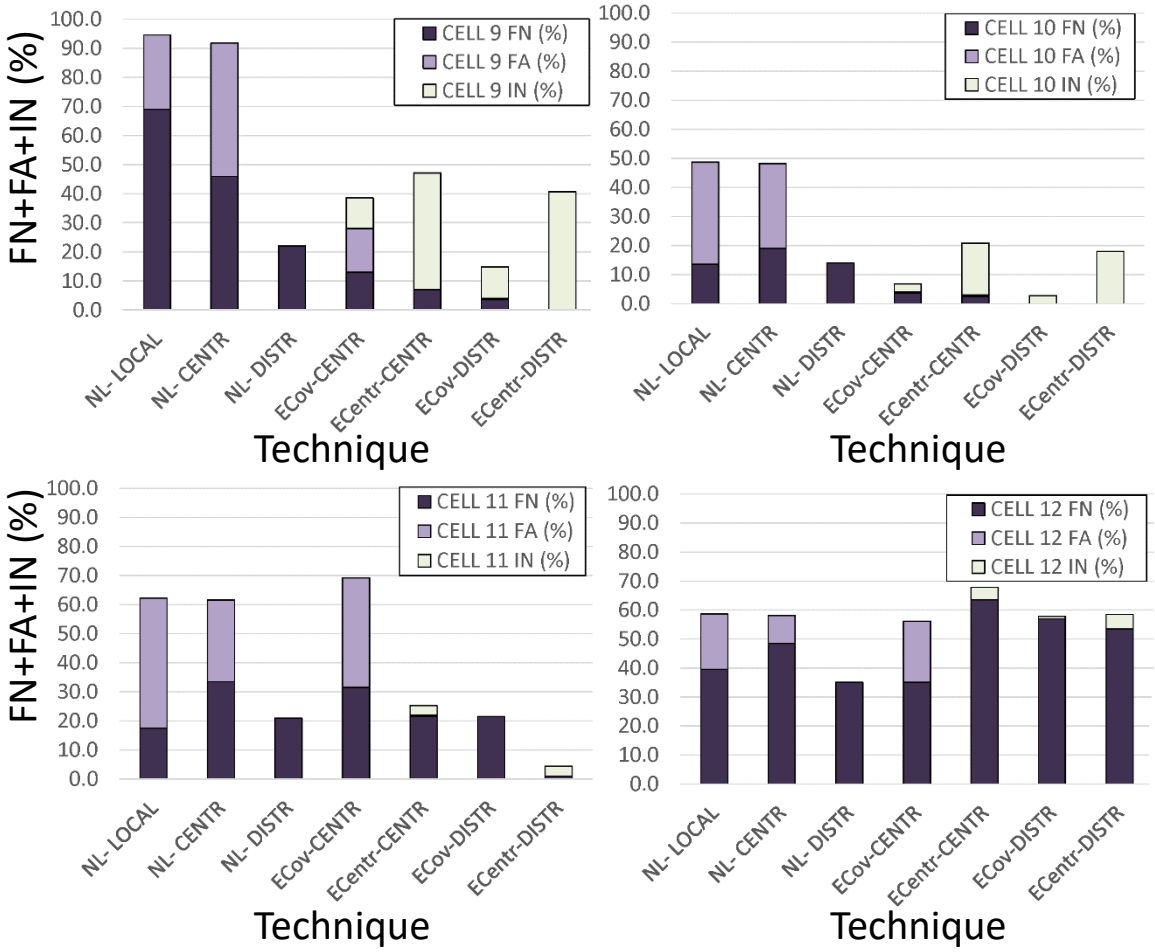
Evaluation - Detection performance

- **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.

DST

Evaluation - Detection performance

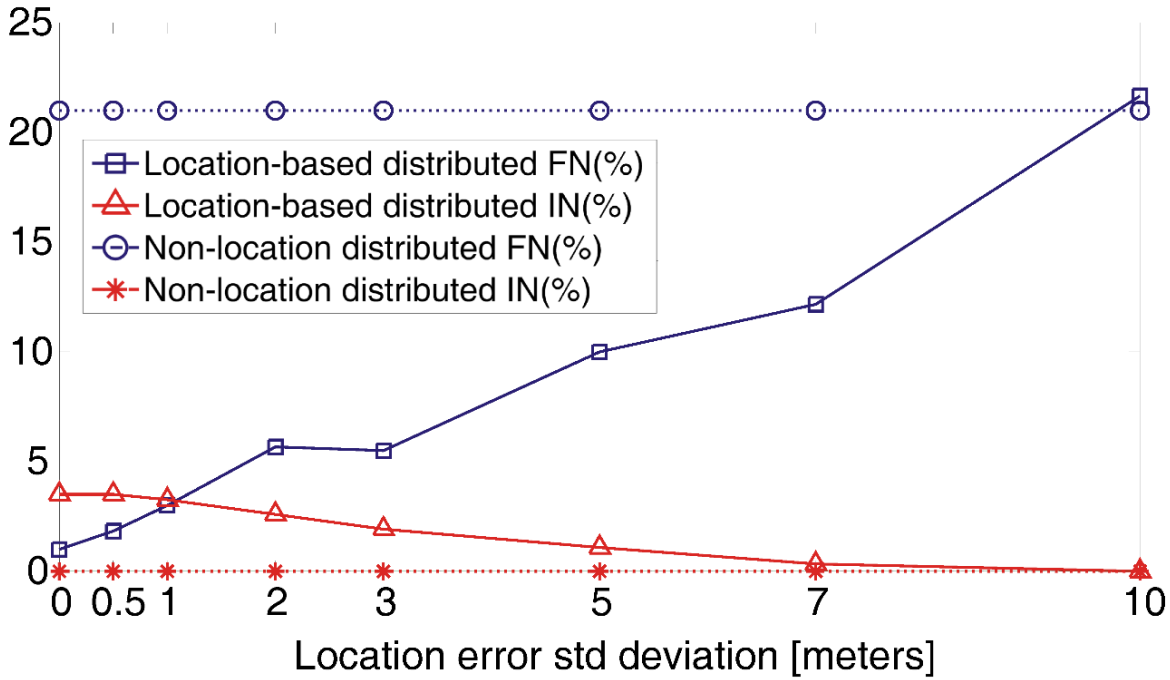
- **Combinations**
  - Local, centralized, distributed.
  - Non-location (NL) or using AOI – center or coverage.
- **Detection performance**
  - FN, FA, IN.
  - Outperforms classic mechanisms except for cell 12 – surrounding by walls → more complex AOI definitions for those cases.



DST

Effects of localization inaccuracies

- **Sleeping cell case - detection performance**
  - Outperforms previous systems even for high localization error (>5 meters).



S. Fortes, R. Barco, and A. Aguilar-Garcia, "Location-based distributed sleeping cell detection and root cause analysis for 5G ultra-dense networks," EURASIP Journal on Wireless Communications and Networking, vol. 2016, pp. 1–18, June 2016.

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CON

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.**

CON