Self-Healing

Chapter 6

Self Healing

Self Healing detects network degradations, identifies counter measures for recovery and executes them

Degradation detection Continuous monitoring

- Anomaly Detection
- Reasoning and decision if degradation exists
- Degradation localization

Diagnosis

- Root cause analysis
- Recovery action options
- Recovery Decision

Recovery and compensation

- Execution of recovery
- Impact Analysis

Outline

Self-healing in 3GPP

Cell Degradation Detection

Cell Degradation Diagnosis and Prediction

Cell Outage Compensation

3GPP use cases

TS32.541: Self-organizing networks (SON); Self-healing concepts and requirements

Self-recovery of NE Software

- In many cases fault can be healed by loading an earlier SW version or configuration to NE

Self-healing of board faults

- The typical fault is a breakdown of a HW element in the NE
- The aim is to solve problem automatically by switching to a standby board when the active board malfunctions

Cell outage detection

- The system is able to detect a cell outage (e.g. sleeping cell) automatically based on alarms, or system variables and performance indicators

Cell outage recovery

- The system recovers cell automatically with best available recovery action

Cell outage compensation (COC)

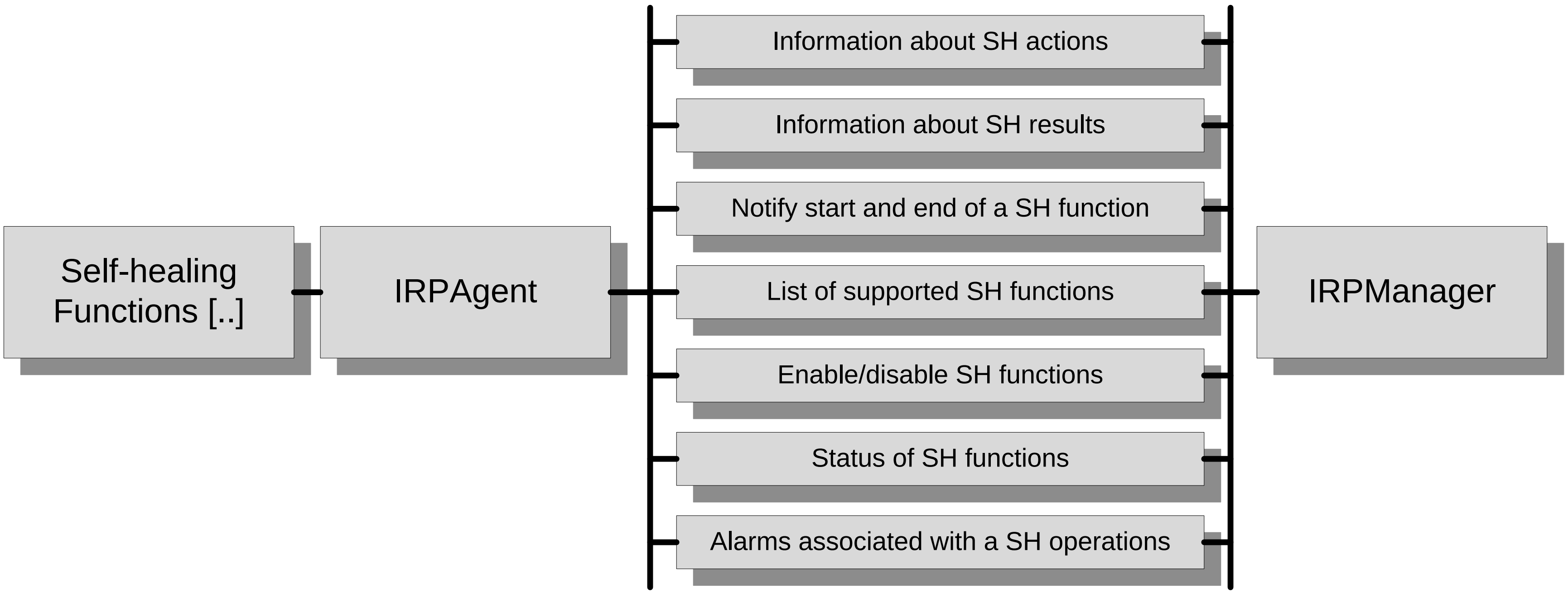
- The system compensates a cell outage automatically to maintain as much as possible normal services to subscribers

Return from cell outage compensation

- The system returns to normal operation after a COC

3GPP Self-healing process and its management

- Self-healing monitoring and managements function
  - Supervises SH process and provides operator with the necessary information
  - Allows operator control
  - Consists of two logical entities:
    - IRPManager in NM
    - IRPAgent in DM below Itf-N
    - IRPAgent enables IRPManager to acquire information about self-healing functions and control them



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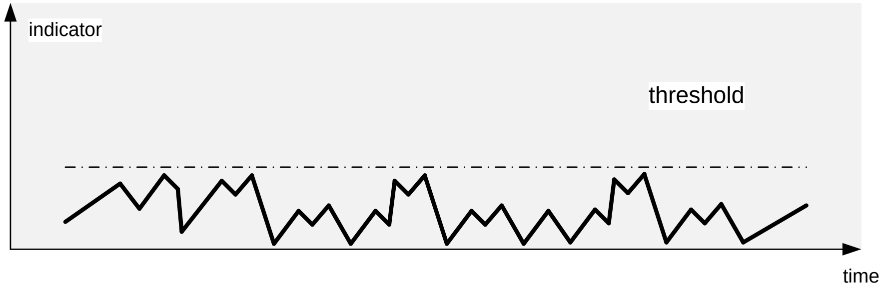
Cell Degradation Detection

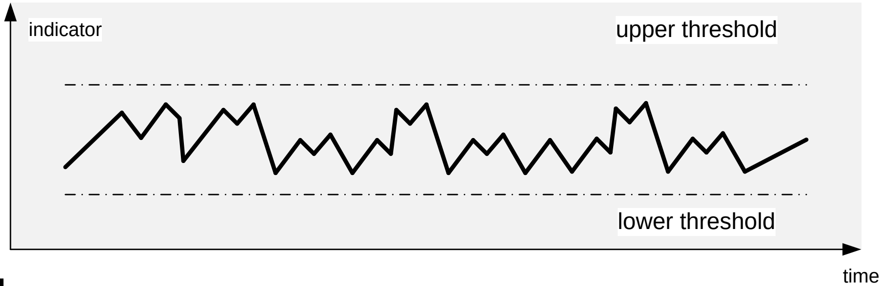
Self-healing related terminology

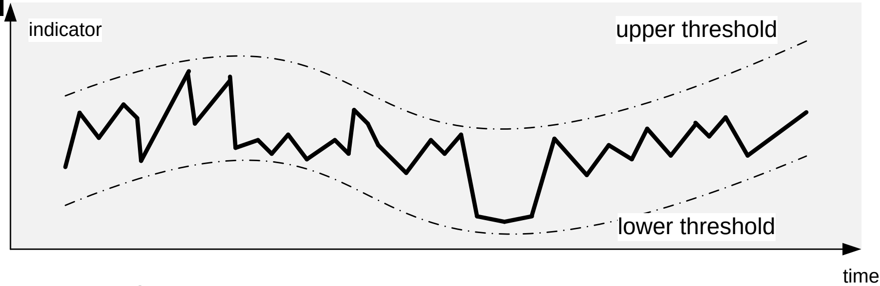
- Symptom – anomalies in performance indicator and presence of alarms. Usually caused by fault, but sometimes by unusual behavior of network. Symptoms are found from performance indicators such as
  - **Counters** – a single value maintained by NE firmware or SW
  - **Key Performance Indicators (KPI)** – one or more counters/measurements are used as inputs to calculate KPI. Often based on standardised formulas
  - **Key Quality Indicators (KQI)** – usually take KPI aggregates to provide broader view of the NW performance. Usually not used to assess cell level performance
  - **Alarms** – NE send towards OAM triggered by predefined events. Usually based on HW/SW faults, but can be based also on threshold violations
- Degradation – significant difference between the expected and actual performance
  - Cellular networks are complex systems and performance indicators derived from them are stochastic in nature
  - Thus in most cases statistical methods are needed to describe either the normal or the faulty operation domains
- Fault – any HW, SW, configuration and planning error that causes degradations

Cell Degradation Detection
Performance indicator profiles

- Performance indicator depends on its temporal structure during healthy operation:
  - **Absolute threshold profile**: performance indicator remaining under a certain threshold. A typical example is failure and fault rates such call drop rate staying below 1%
  - **Statistical profile**: performance indicator oscillating around an expected (mean) value. A trivial profile can be with upper and lower thresholds
  - **Time-dependent profile**: performace indicator showing temporal periodicity, usually driven by user behaviour.
- Not all indicators exhibit strong periodicity. An example is throughput which usually shows strong temporal periodicity at traffic aggregation nodes but much weaker periodicity at individual cell level







Cell Degradation Detection

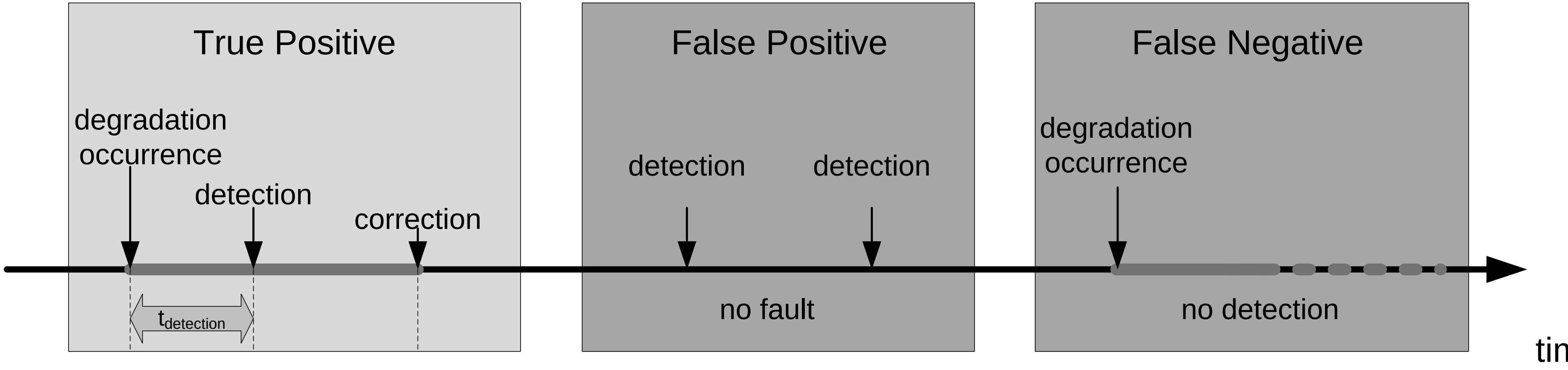
- Anomaly detection is achieved in three main steps:
  - Performance indicators must be defined that are of interest
  - The normal, expected operation domain must be defined for each indicator
  - During operation actual values of indicators must be evaluated against the corresponding profile
- Today, collection of performance indicators, profile construction, evaluation of actual performance information against profiles are all done automatically
  - These detection procedures are not reliable and producing lots of “false positive” alarms
  - Thus the main goal of degradation detection research is to improve this classification capability
- More elaborate statistical models can be applied to define the normal operation domain of indicators in order to improve automated detection methods

Cell Degradation Detection

- Automated anomaly detection method can be classified into two major classes
  - Univariate techniques:
    - Algorithms based on the past observation of the indicator and on a statistical model for the normal domain
    - These methods are not capable to differentiate anomalous situations caused by real faults and unusual cell behaviour
    - Detection accuracy depends more on the underlying statistical model than the actual detection decision → challenging task is to construct/learn a good profile
    - Once profile is in place, the decision whether the actual performance is according to the profile or not, is a relatively simple task
  - Multivariate anomaly detection:
    - These methods are capable to assess the performance of a whole cell as multiple indicators are processed and evaluated against each other

Cell Degradation Detection

- To validate performance algorithms metrics for anomaly detection performance are needed
  - Detection accuracy can measured from
    - **True positives** – detection of actual anomaly
    - **False positive** – notification of anomaly when there is no such problem
    - **False negative** – missed detection of anomaly
  - Detection delay
    - Time interval from the actual anomaly occurrence until it is detected
      - Detection delay computed for true positives and anomaly detected during its duration
      - It is assumed that detection outside anomaly duration is seen as false positive



Cell Degradation Detection

- Other relevant metrics
  - Severity indication accuracy – Anomaly detector could indicate severity of detected anomaly
  - Signalling overhead – Fault management algorithms could introduce signalling in the transport (between eNBs (X2), eNB and MME(S1) and OSS (Itf-S)) network and in radio interface (between UE and eNB)
  - Processing overhead – Detection algorithm can create processing overhead that amount depends on e.g. the size of the input data

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Cell Degradation Diagnosis and Prediction

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Cell Degradation Diagnosis and Prediction

- Today, diagnosis is typically still manual based on domain knowledge gained by troubleshoot expert
- Increasing size and complexity of cellular network calls for automated troubleshooting tools
  - Reduce the time required to find the fault that causing a certain problem
  - Enhance network performance as degradation time will be limited significantly
  - Reduce cost associated with troubleshooting as less personnel with lower skill level is capable to do the same work
- Automation of diagnosis is an evolutional process
  1. Learning/customization phase where knowledge of experts is used to train the automated system.
  2. Assistance phase where the expert system is capable to give advice to troubleshooting experts about the most probable faults but the final decision is still imade by human engineers
  3. System taking over tasks from human operators and trigger corrective action automatically
  - A long term vision is that human operators need to supervise the automated diagnosis system by defining high level policies guiding the automated troubleshooting process while leaving the details to the expert diagnosis system

Cell Degradation Diagnosis and Prediction

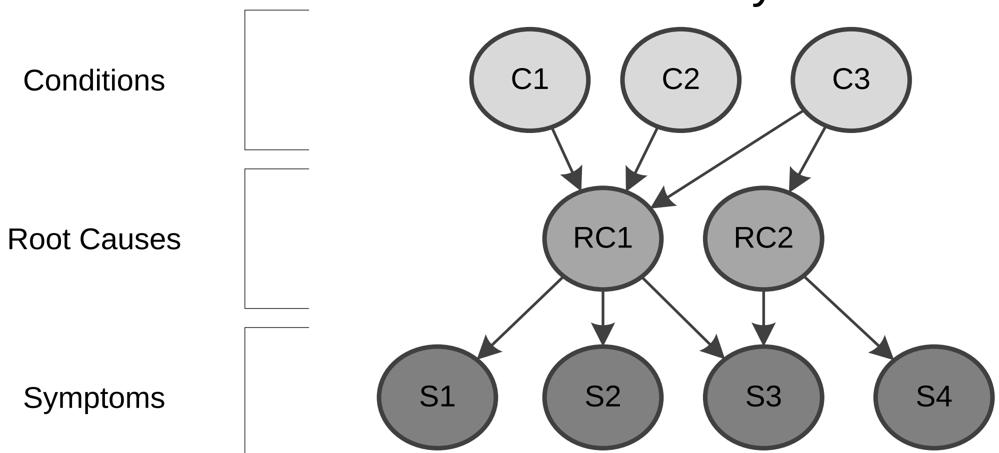
- The most critical step in this process is the association between observations and root causes. This is commonly referred to as **expert knowledge**
- Most automated methods focus on the collection and integration of expert knowledge to a framework that is capable to perform the same reasoning. **This is a machine learning problem**
- Expert system must beable to to adapt to diffenrent environments and to be able to specialize itself to learn the particularities of the network it diagnoses

Rule base systems

- Rule based systems are simple systems based on IF(A)-THEN (B) rules. For example
  - IF HW alarm is received THEN check the hardware component annotated by the alarm
  - IF HOfailures > threshold THEN check if handovers occur according to the planned adjacencies
- Rule based systems involve some drawbacks in complex systems as cellular networks
  - too many rules are required to catch every possible problem making rule sets unmanageable and inference slow
  - usually troubleshooting experts are uncertain in their reasoning as a set of symptoms can indicate several problems each with some probability
    - This uncertainty cannot be expressed by rule based systems.
- Rule base system could be extended by using codebook based reasoning
  - This approach utilizes the fact that every fault in a complex system has its unique signature
  - The framework stores the signatures of known faults and matches actual system information to the stored information.
  - The diagnosis looks for the closest matching signature thus it does not require an exact match

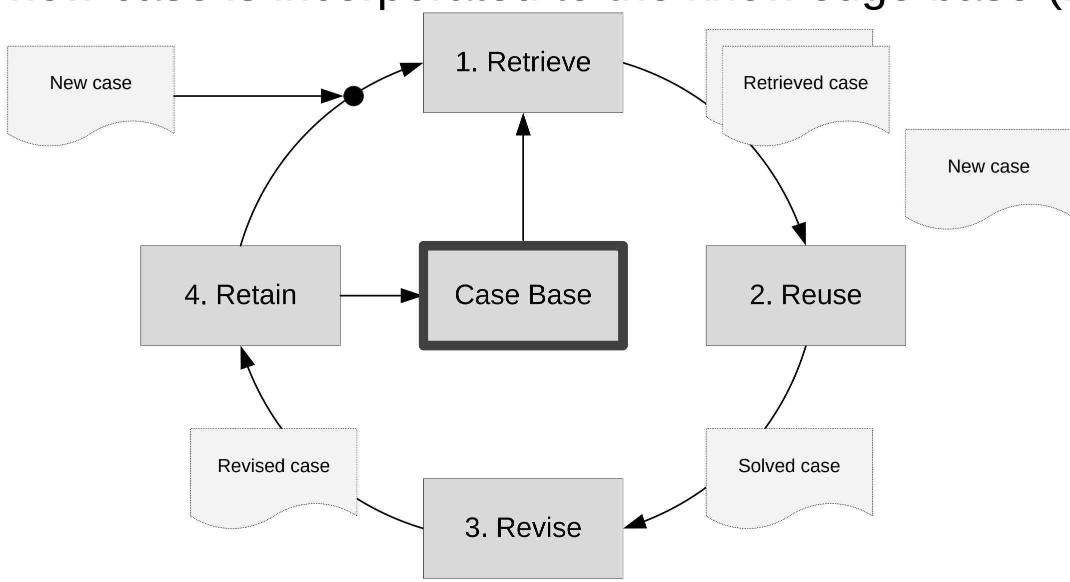
Bayesian networks

- Bayesian networks (BNs) are based on Bayes' theorem which is able to expresses the conditional probability of a random variable given the value of another variable
  - Extended to represent conditional probability dependencies between several random variables visualized by a directed, acyclic graph
    - Conditions: global properties of the environment (context for faults and symptoms)
    - Root causes: fault to detect
    - Symptoms: Anomaly in measured performance indicators
  - Probability table between root causes and symptoms is created based on expert knowledge
  - As BNs can evolve over time, diagnosis accuracy improves when more cases are observed
  - Drawback of BNs is that models are relatively difficult to build



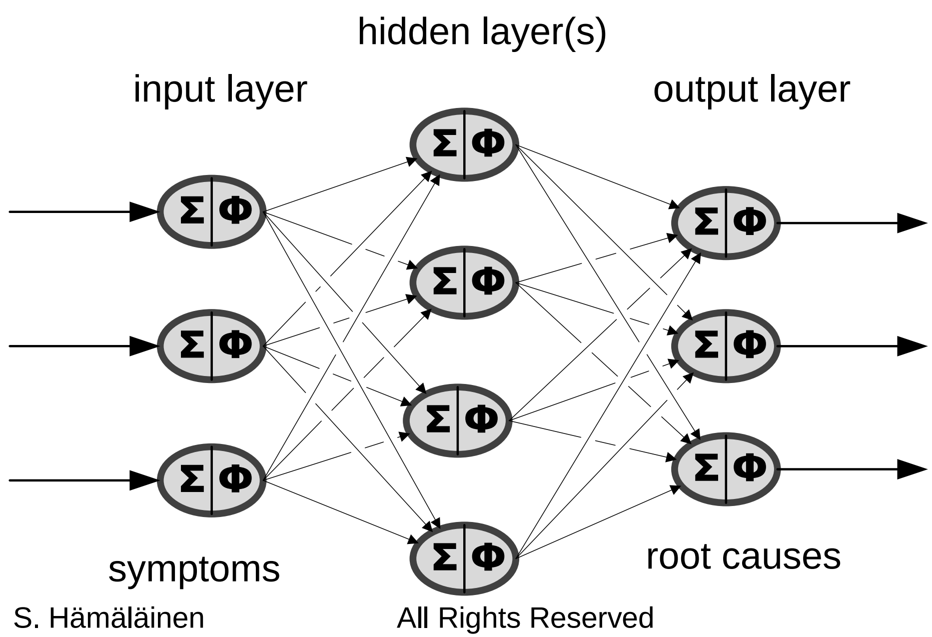
Case based reasoning

- A problem with BN approach comes from the fact that in mobile network faults are relatively rare, very diverse and network may change over time
  - BN is difficult to teach and it maybe unstable
- Case based reasoning (CBR) is another approach in which system learns from prior observations and build ever improving database from them
  - Every time a new fault appears the system retrieves the most similar prior case and the diagnosis result associated with it
  - The most probable root cause for the new fault will be the root cause of the most similar earlier case (retrieve and reuse)
  - Then the solution of the new case is revised to see if it is correct. Upon correct solution the new case is incorporated to the knowledge base (revise and retain)



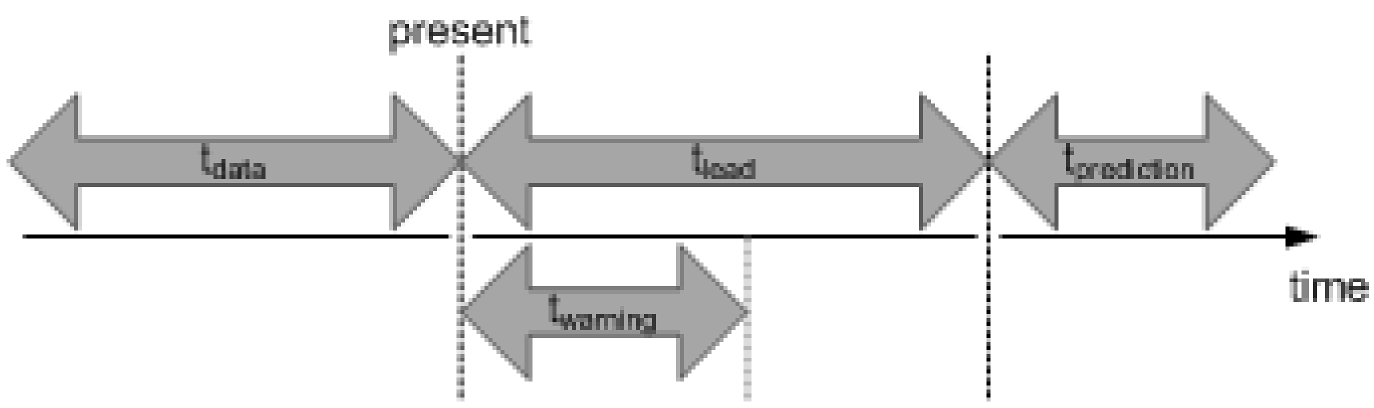
Neural networks

- Neural networks (NN) are represented by a set of interconnected nodes – artificial neurons – organised in layers
- Every neuron is connected to all neurons in the next layer
  - Each node pair is associated a weight that defines strength of association
  - Neural network can be trained to learn weights
- During operation input values are fed into node and weighted sum is calculated and put as output of node trough a transfer function
- In fault diagnosis domain NN inputs are symptoms and outputs are root-causes, while associations and their weights are expert knowledge



Prediction

- Prediction aims to predict behavior of the dynamic environment based on *online time failure prediction methods*
- Prediction can be seen early detection and diagnosis based on early signs of deteriorations
- Prediction aims to detect potential problems before actual fault (alarm) would occur in future (during time t_{lead})
  - Based on current and prior system state (over time t_{data})
  - Prediction is valid for certain time ($t_{prediction}$)
  - Time required to react and act ($t_{warning}$)should be less than lead time, as otherwise warning would come after actual fault



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Cell outage compensation

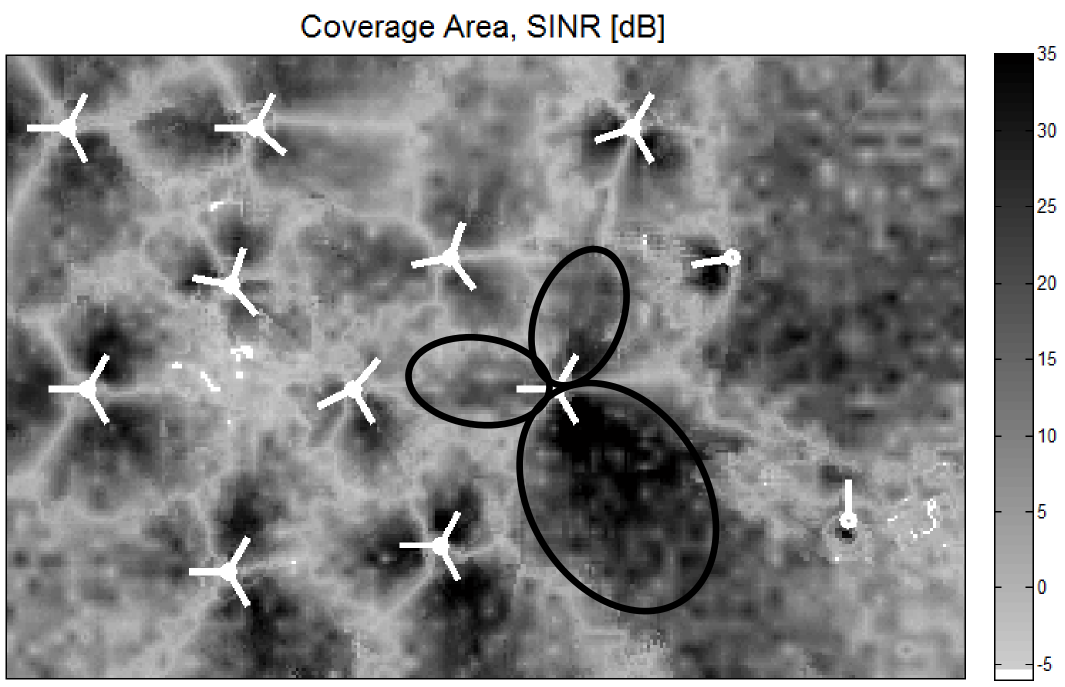
- Cell outage due to failure leads to sudden loss of coverage. This leads further to low network quality, lost revenue and increased churn
- Therefore quick reaction is needed. COC can be based on e.g.
  - TX power optimisation
  - Tilt optimisation
  - Beam steering
  - Overlapping coverage with HeNB
- Cell outage can be also due to energy savings

Means of COC

- As cell outage leads to service unavailability it is important to perform COC quickly – typically with one step optimization
  - This leads to worse performance than e.g. step wise tilt optimisation for CCO
  - Coarse optimisation with COC can be fine tuned with CCO
- COC means
  - Power optimisation:
    - A simple method
    - Usually in coverage limited case maximum powers are already used
    - In interference limited case overlap is sufficient with out COC
  - Tilt optimisation
    - Requires RET enabled sites
    - In coverage limited case minimum tilts are already used
- When coverage area of a neighbour cell is modified for COC purposes, geographical neighbourships could change leading to
  - Possible PCI collisions. Therefore PCI allocation should be launched
  - Missing neighbor relations for handover. Therefore ANR should be launched

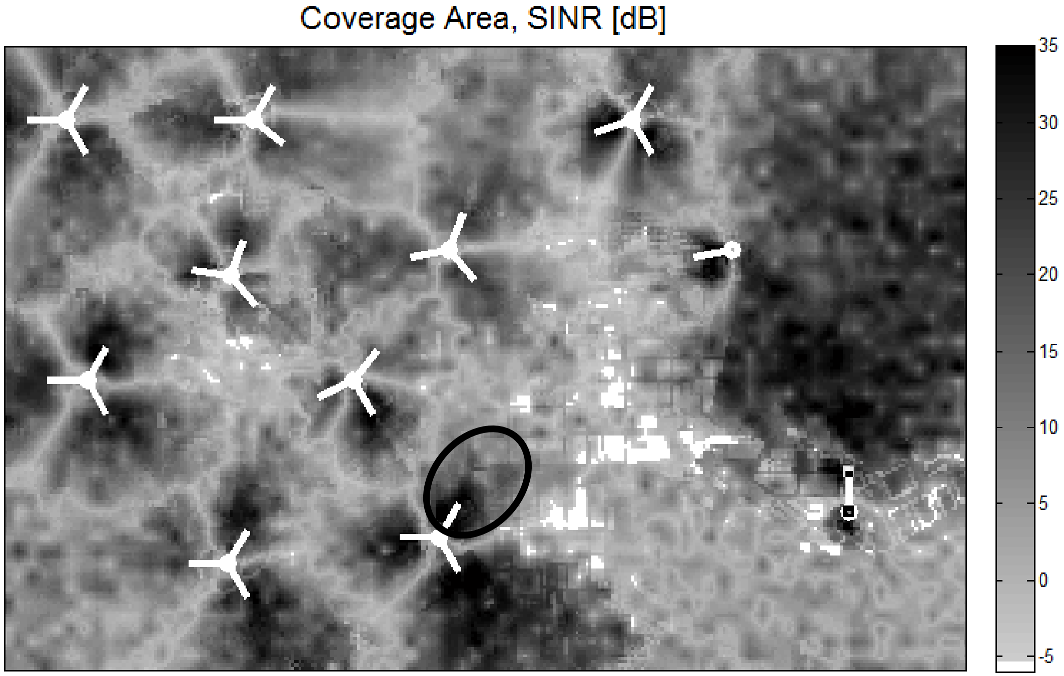
COC example

- A typical cell outage compensation scenario assuming a malfunctioning 3-sectorized base station
  - Initially, a realistic network deployment scenario is given in which network is working normally. In this scenario used power levels have been optimised to provide energy saving, therefore maximum power levels are not used



COC example

- One of the base stations is malfunctioning, so that cell outage occurs. Therefore, cell outage compensation should be triggered through the neighbouring cells
  - Cell used for compensation shown with circle



COC example

- Transmission power and antenna tilts are optimised for the cell outage compensation and almost whole outage area has been covered by neighbouring cells.
  - The coverage area after compensation is shown for one of the cells used for compensation.