Self-organisation in future mobile cellular networks

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OUTLINE

- Introduction
- Drivers
- Vision
- Expected gains
- Use cases
  - Packet scheduling
  - Admission control
  - Cell outage management
  - Reduction of energy consumption
- Challenges
- Approaches
- Who is who?
- Concluding remarks

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INTRODUCTION

Wikipedia

Self-organisation is a process of attraction and repulsion in which the internal organization of a system, normally an open system, increases in complexity without being guided or managed by an outside source.

Another attempt

(in the specific context of communication networks)

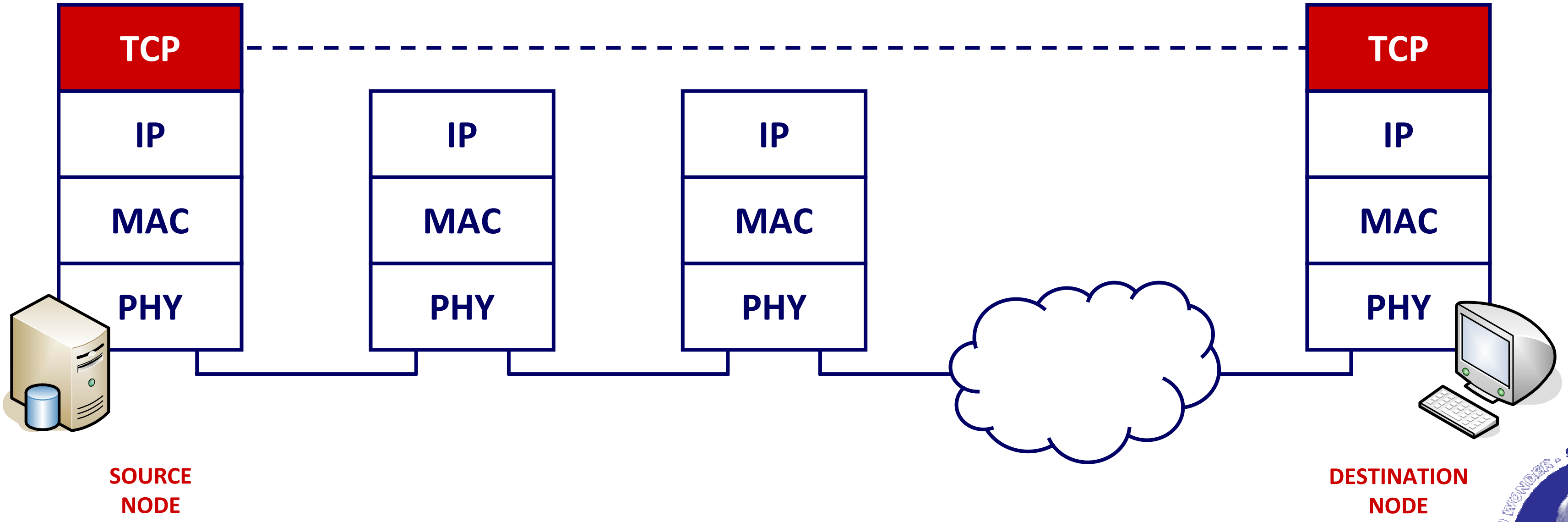
Self-organisation is the automated (without human intervention) adaptation or configuration of network parameters (in a broad sense), in response to observed changes in the network, traffic, environment conditions and/or experienced performance.

Some examples may help …

SELF-ORGANISATION IN EXISTING NETWORKS

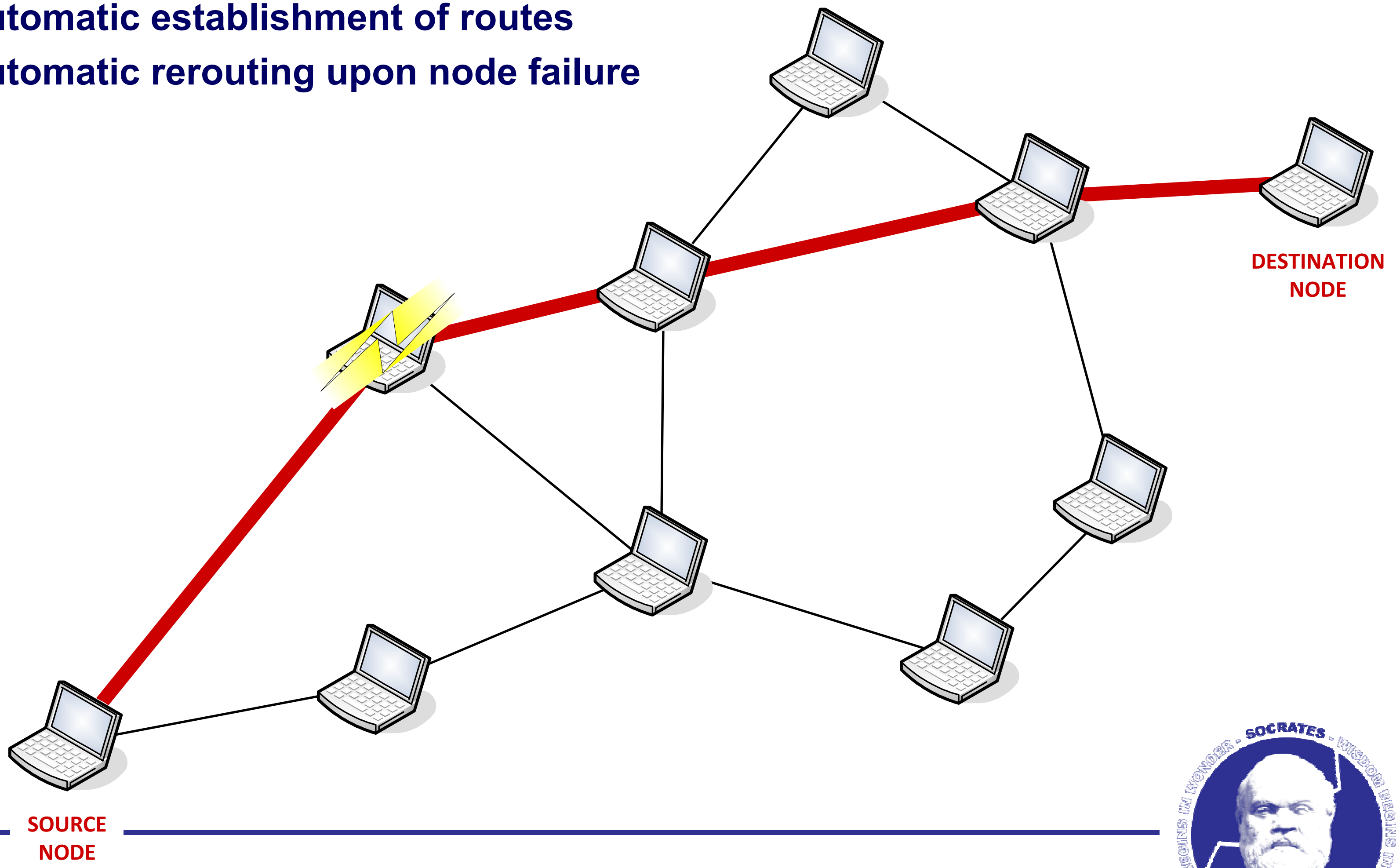
- **Example 1: TCP (Transmission Control Protocol)**
  - **Operates end-to-end on the transport layer**
  - **Automatically adapts source transfer rate to end-to-end congestion level**
  - **Slow start phase is followed by congestion avoidance phase**
    - **AIMR → Additive Increase, Multiplicative Decrease**

→ 'Optimal', fair bandwidth sharing



SELF-ORGANISATION IN EXISTING NETWORKS

- **Example 2: ‘Routing in ad hoc networks’**
  - Automatic detection of connectivity
  - Automatic establishment of routes
  - Automatic rerouting upon node failure



SELF-ORGANISATION IN EXISTING NETWORKS

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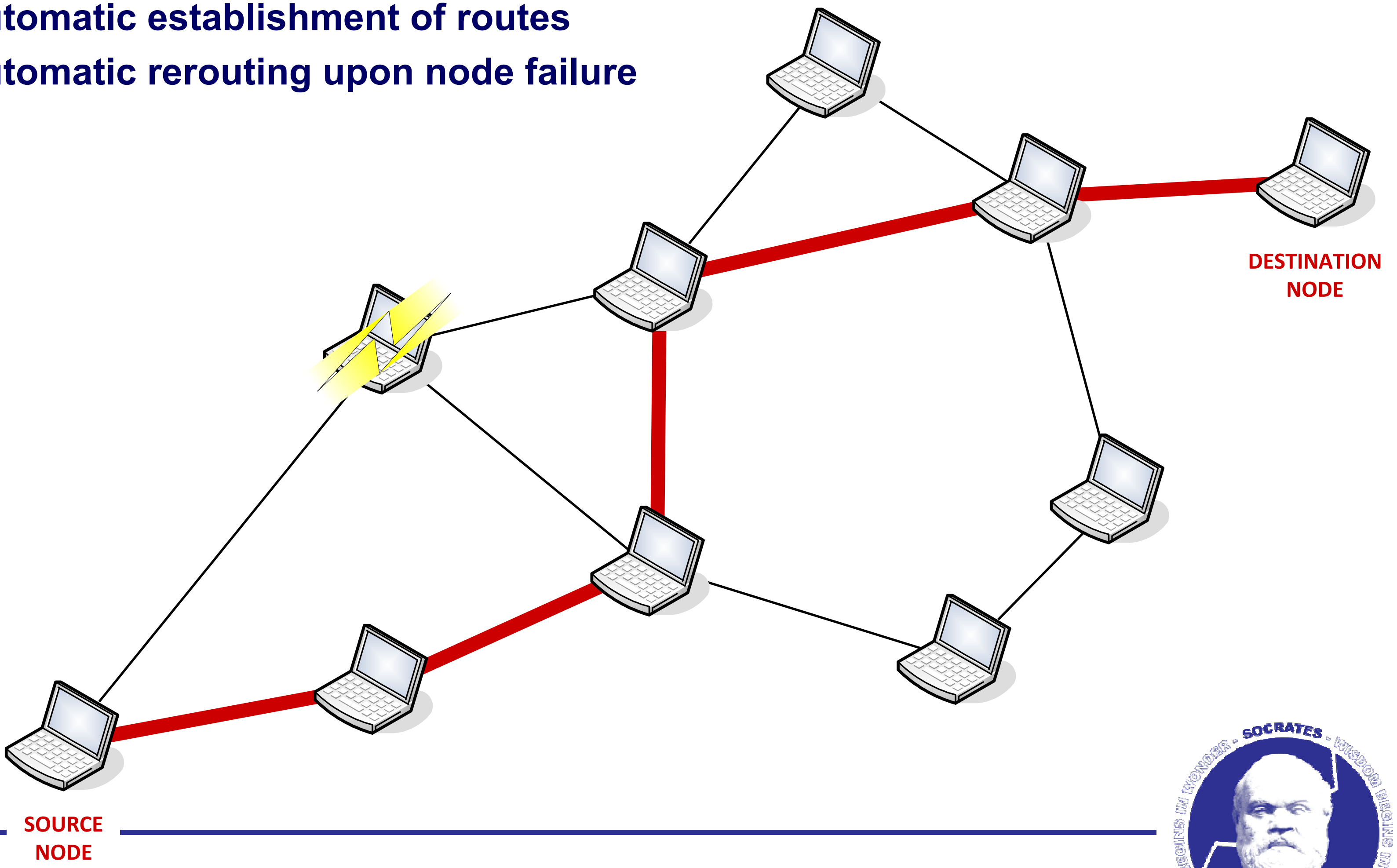
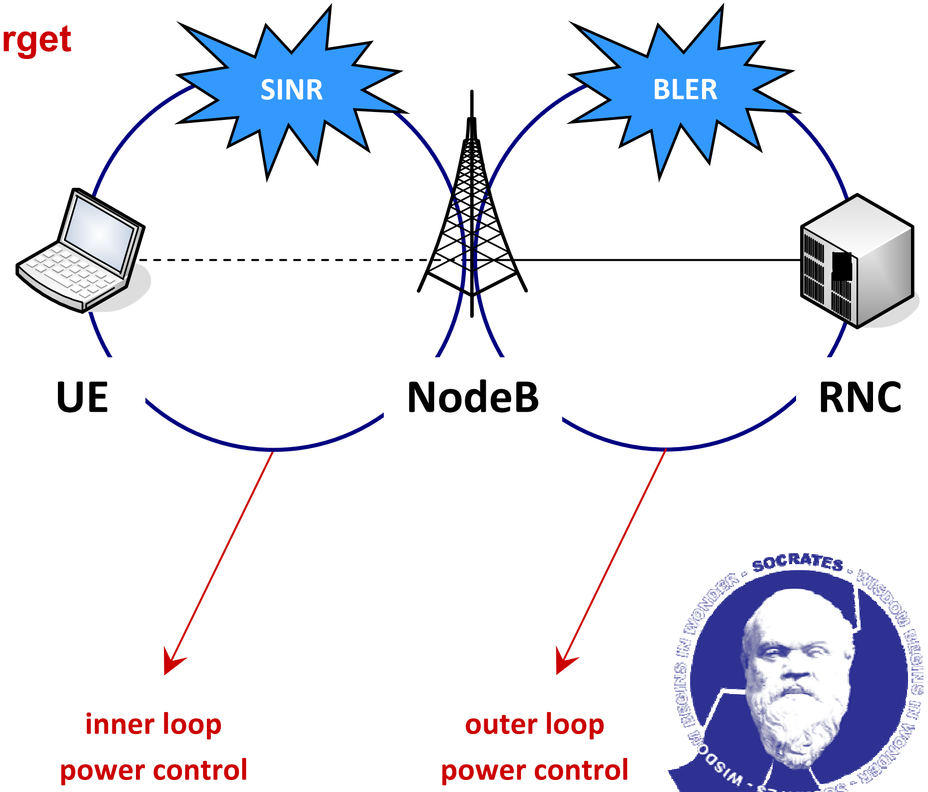


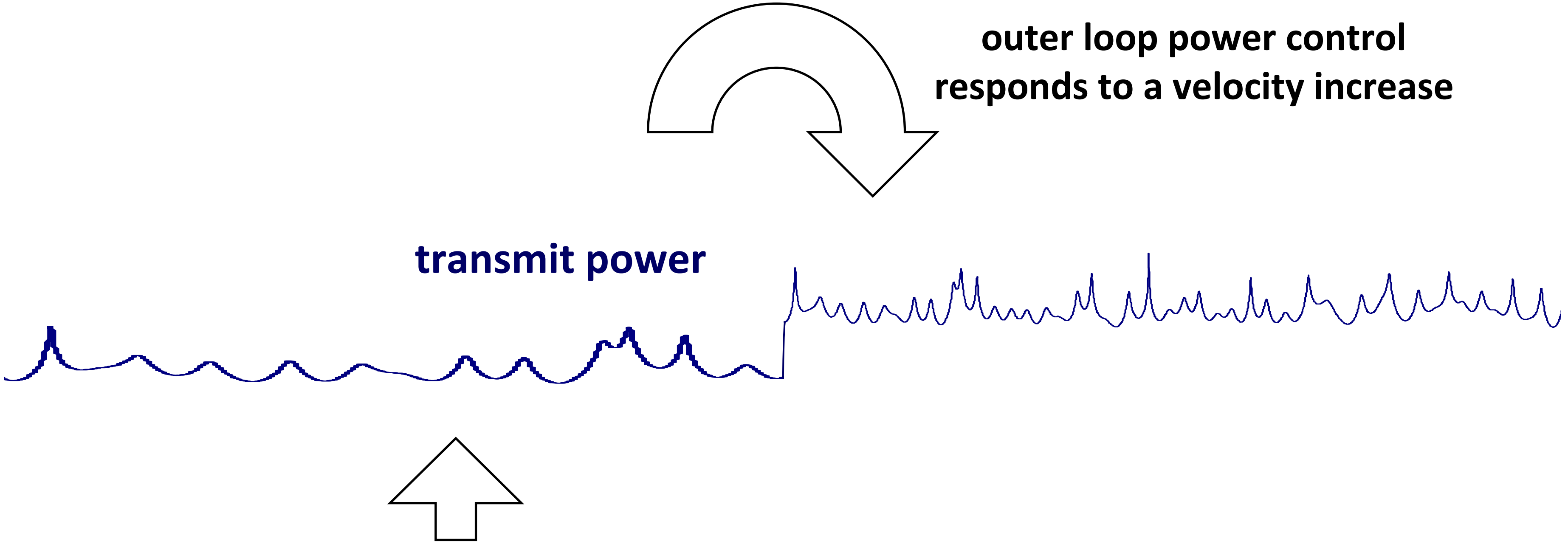
SELF-ORGANISATION IN EXISTING NETWORKS

- **Example 3: 'Uplink transmit power control in UMTS networks'**
  - **1st Self-optimisation loop**
    - **Adjust transmit power to meet SINR target**
    - **Responds to e.g. multipath fading variations**
  - **2nd Self-optimisation loop**
    - **Adjust SINR target to meet BLER target**
    - **Adapts to e.g. user velocity**



SELF-ORGANISATION IN EXISTING NETWORKS

- **Example 3: 'Uplink transmit power control in UMTS networks'**



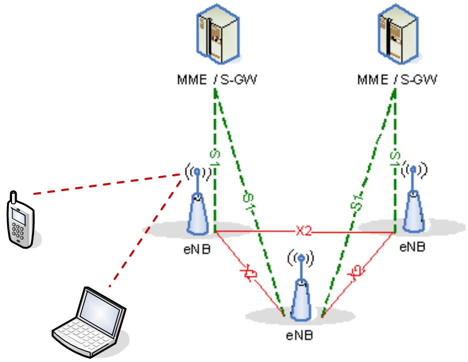
outer loop power control
responds to a velocity increase

transmit power

inner loop power control
follows multipath fading

INTRODUCTION

- Context of this presentation
  - Mobile cellular communications networks
  - LTE access technology
    - Long Term Evolution (E-UTRAN)
    - Currently under standardisation
    - Focus on radio access network



2011?	LTE
2006	+ HSPA
2003	UMTS
2001	+ GPRS
1994	GSM
1989	NMT 900
1985	NMT 450
1980	OBLB

INTRODUCTION

- Current networks are largely manually operated
  - Manual configuration of sites
  - Radio (resource management) parameters updated weekly/monthly
    - Time-intensive experiments with limited operational scope
  - Delayed, manual and poor handling of cell/site failures
  - (Non-)automated planning tools used to select sites, radio parameters
    - ‘Over-abstraction’ of applied technology models

- Future wireless access networks will exhibit a significant degree of self-organisation
  - Self-configuration, self-optimisation, self-healing, …

- Broad attention
  - 3GPP, NGMN, EU projects (e.g. Gandalf, E^3, SOCRATES), literature …
  - Evolutionary vs. revolutionary approach

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- **Drivers for self-organisation**
- Vision
- Expected gains
- Use cases
  - Packet scheduling
  - Admission control
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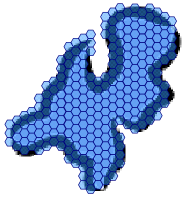
DRIVERS

- Technogical perspective
  - Complexity of future/contemporary wireless access networks
    - Multitude of tuneable parameters with intricate dependencies
    - Multitude of radio resource management mechanisms on different time scales
    - Complexity is needed to maximise potential of wireless access networks
  - Higher operational frequencies
    - Multitude of cells to be managed
  - Growing suite of services with distinct char'tics, QoS req'ments
  - Heterogeneous access networks to be cooperatively managed

  → *labour-intensive operations delivering suboptimal solutions!*



- Enabler
  - The multitude and technical capabilities of base stations and terminals to perform, store, process and act upon measurements increases sharply

DRIVERS

- **Market perspective**
  - **Increasing demand for services**
  - **Increasing diversity of services**
    - **Traffic characteristics, QoS requirements**
  - **Need to reduce time-to-market of innovative services**
    - **More ‘flexibility’**
    - **Reduce operational hurdles of service introduction**
  - **Pressure to remain competitive**
    - **Reduce costs (OPEX/CAPEX)**
    - **Enhance resource efficiency**
    - **Keep prices low**

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  - Automatic neighbour cell list generation
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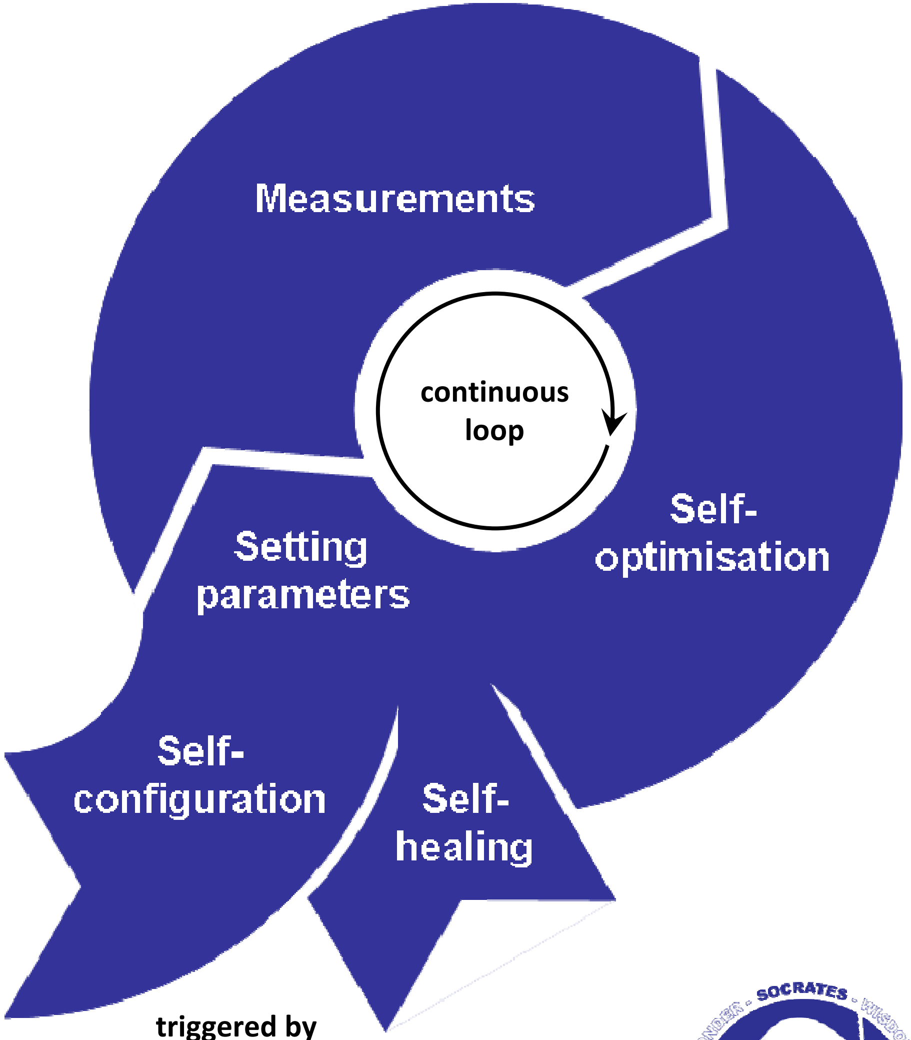
VISION

- **Minimise human involvement in network operations**
- **Significant automation of network operations**
- **Key components**
  - **Self-configuration**
  - **Self-healing**
  - **Self-optimisation**



Measurements

continuous loop

Setting parameters

Self-optimisation

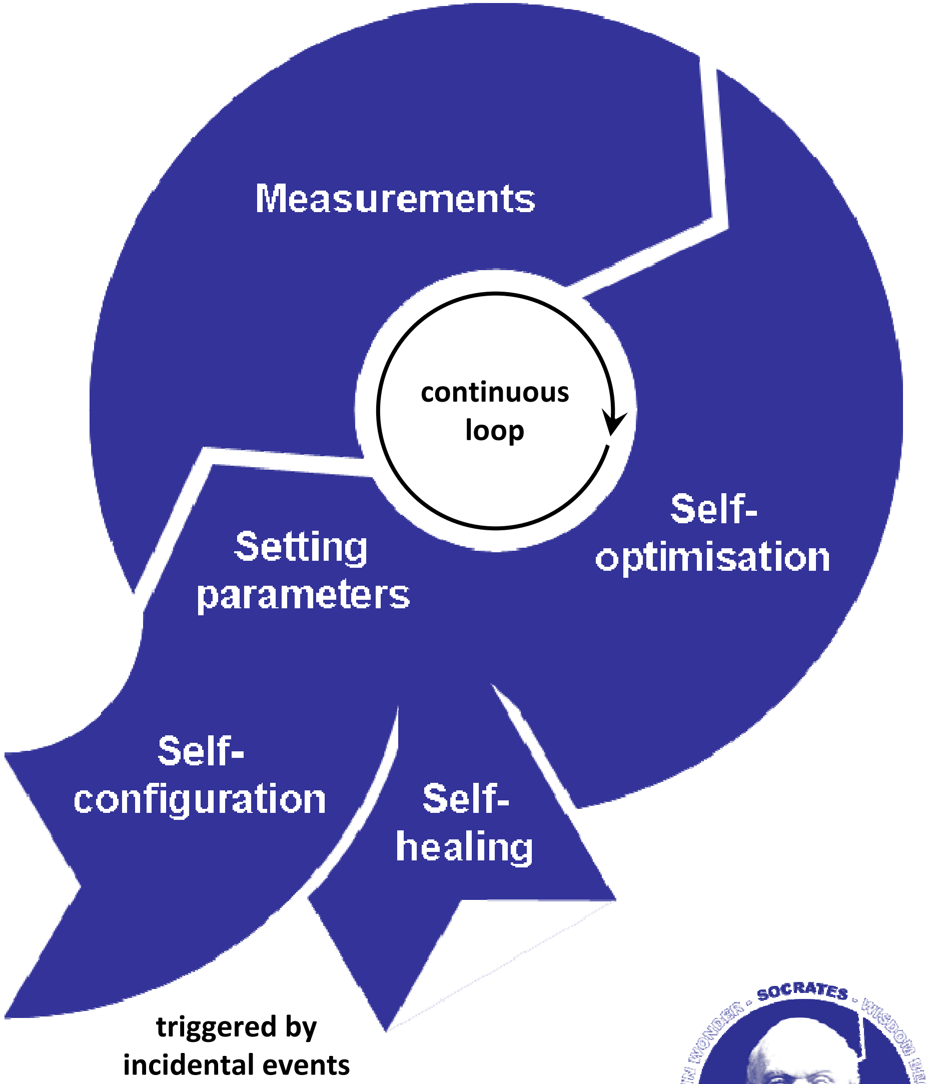
Self-configuration

Self-healing

triggered by incidental events

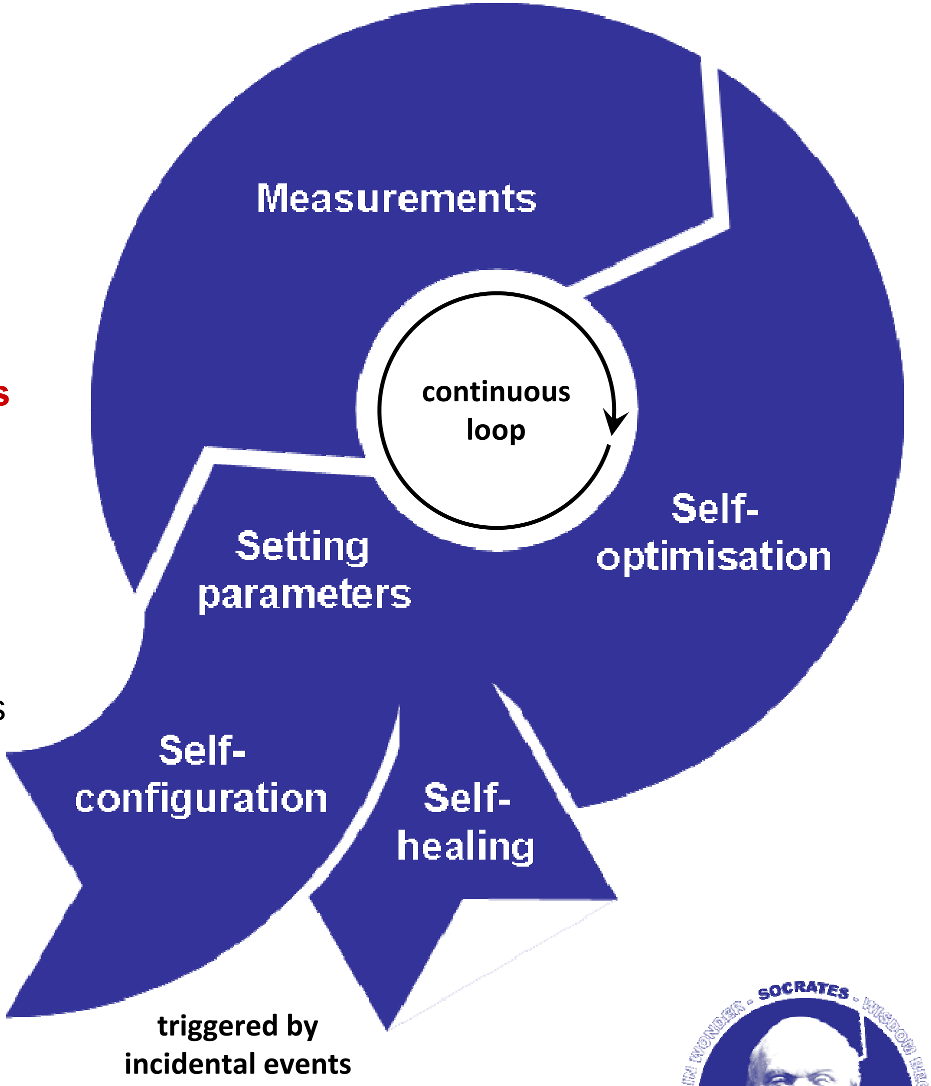
VISION

- **Self-configuration**
  - Incidental, intentional events
  - ‘Plug and play’ installation of new base stations and features
    - Download of initial radio network parameters, neighbour list generation, transport network discovery and configuration, …
    - Starting point for self-optimisation
- **Self-healing**
  - Incidental, non-intentional events
  - Cell outage detection
    - Alarm bells
    - Triggers compensation
  - Cell outage compensation
    - Automatic minimisation of coverage/capacity loss



VISION

- **Self-optimisation**
  - **Continuous loop**
  - **Measurements**
    - **Performance indicators**
    - **Network, traffic, mobility, propagation conditions**
    - **Gathering via UEs, eNodeBs, probes**
  - **Automatic tuning**
    - **Smart algorithms process measurements into parameter adjustments**
      - E.g. tilt, power, RRM param’s, …
      - In response to observed changes in conditions and/or performance
      - In order to provide service availability/quality most efficiently
  - **Triggers/suggestions in case capacity expansion is unavoidable**



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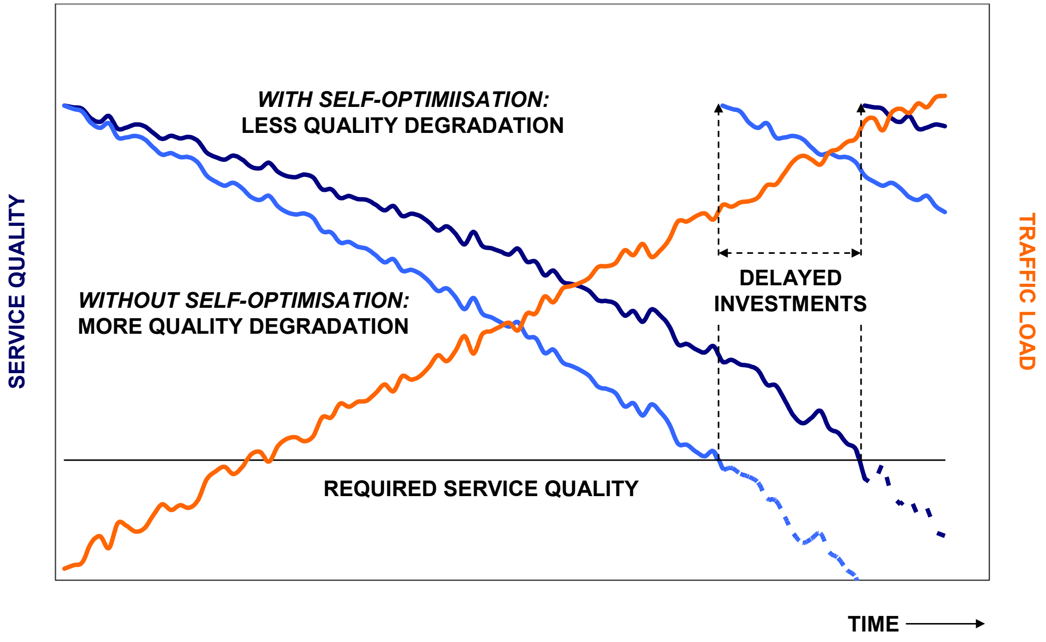
EXPECTED GAINS

- **OPEX reductions …**
  - Primary objective!
  - Less human involvement in
    - Network planning/optimisation
    - Performance monitoring, drive testing
    - Troubleshooting
  - About 25% of OPEX is related to network operations
    - x00 million € savings potential per network

EXPECTED GAINS

- … and/or CAPEX reductions …
  - Via delayed capacity expansions
  - Smart eNodeBs may however be more expensive
- … and/or performance enhancements
  - Enhanced service availability, service quality

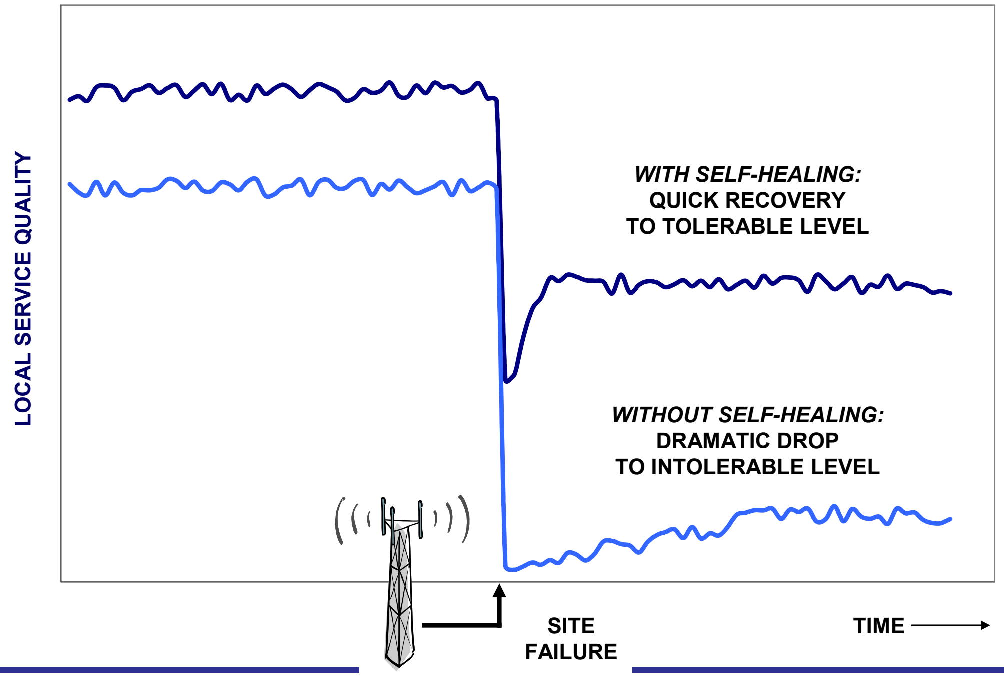
IMPACT OF 'SELF-OPTIMISATION'



EXPECTED GAINS

- … and/or CAPEX reductions …
  - Via delayed capacity expansions
  - Smart eNodeBs may however be more expensive
- … and/or performance enhancements
  - Enhanced service availability (robustness, resilience), service quality

IMPACT OF 'SELF-HEALING'



WITH SELF-HEALING:
QUICK RECOVERY
TO TOLERABLE LEVEL

WITHOUT SELF-HEALING:
DRAMATIC DROP
TO INTOLERABLE LEVEL

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USE CASES

- FP 7 SOCRATES
  - Self-Optimisation and Self-Configuration in Wireless Networks
- Evolutionary approach towards self-organisation
  - Take current architecture as starting point
    - Works quite well, when parameters are properly tuned …
  - ‘Make’ existing functionalities self-*
    - E.g. RRM mechanisms, cell outage management, …
    - Determine actual need for self-* by sensitivity analysis
    - Algorithms for ‘automatic’ adaptation of parameters
  - Required architectural modifications → impact on standardisation
    - Measurements, interfaces, signaling, …
- Many ‘use cases’ defined
  - Stand alone functionalities
  - Interacting functionalities

USE CASES

- **Non-exhaustive use case list**
  - **Self-optimisation**
    - **Radio network optimisation**
      - Interference coordination
      - Self-optimisation of physical channels
      - RACH optimisation
      - Self-optimisation of Home eNodeBs
    - **GOS/QoS-related optimisations**
      - AC/CC/PS optimisation
      - Link level retx scheme optimisation
      - Coverage hole detection/compensation
    - **Handover related optimisation**
      - Handover parameter optimisation
      - Load balancing
      - Neighbour cell list
    - **Others**
      - Reduction of energy consumption
      - TDD UL/DL switching point
      - Management of relays and repeaters
      - Spectrum sharing
      - MIMO
  - **Self-configuration**
    - **Automatic NCL generation**
    - **Intell. selecting site locations**
    - **Automatic generation of default parameters for NE insertion**
    - **Network authentication**
    - **Hardware/capacity extension**
  - **Self-healing**
    - **Cell outage prediction**
    - **Cell outage detection**
    - **Cell outage compensation**

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USE CASE: PACKET SCHEDULING

- **Sensitivity analysis**
  - **Impact of traffic- and system characteristics on optimal setting of PS parameters**

- **Reference packet scheduling algorithm:**
  - **LTE downlink scheduler (time, frequency)**
  - **Supports real-time (video telephony) and non real-time (data) traffic**
  - **Contains elements of proportional fairness and packet due dates**

$$P_{i,c}(t) = \rho_{service} \underbrace{\frac{R_{i,c}(t)}{\underline{R}_i(t)}}_{\text{channel adaptivity factor}} \cdot \underbrace{\left(1+\frac{W_i(t)}{T_i - W_i(t)}\right)^{\xi}}_{\text{packet urgency factor}}$$

USE CASE: PACKET SCHEDULING

- **Calculation of packet priority levels (at every TTI)**
  - **For all users *i* with packets in buffer, for all subchannels *c*:**

$$P_{i,c}(t) = \rho_{service} \underbrace{\frac{R_{i,c}(t)}{\underline{R}_i(t)}}_{\text{channel adaptivity factor}} \cdot \underbrace{\left(1+\frac{W_i(t)}{T_i - W_i(t)}\right)^{\xi}}_{\text{packet urgency factor}}$$

- $R_{i,c}(t)$: potential bit rate at which user *i* can be served on subchannel *c* at TTI *t*
- T_i: max allowed delay for packets of user *i*
- $W_i(t)$: delay of HOL packet of user *i* at TTI *t*
- $\underline{R}_i(t)$: exp. smoothed average bit rate obtained by user *i*

$$\underline{R}_i(t) = (1-\alpha)\underline{R}_i(t-1) + \alpha R_i(t-1)$$

- **Two main parameters**
  - **α: exponential smoothing parameter**
  - **ξ: parameter to set the importance of the urgency factor**

USE CASE: PACKET SCHEDULING

- **LTE system level simulator**

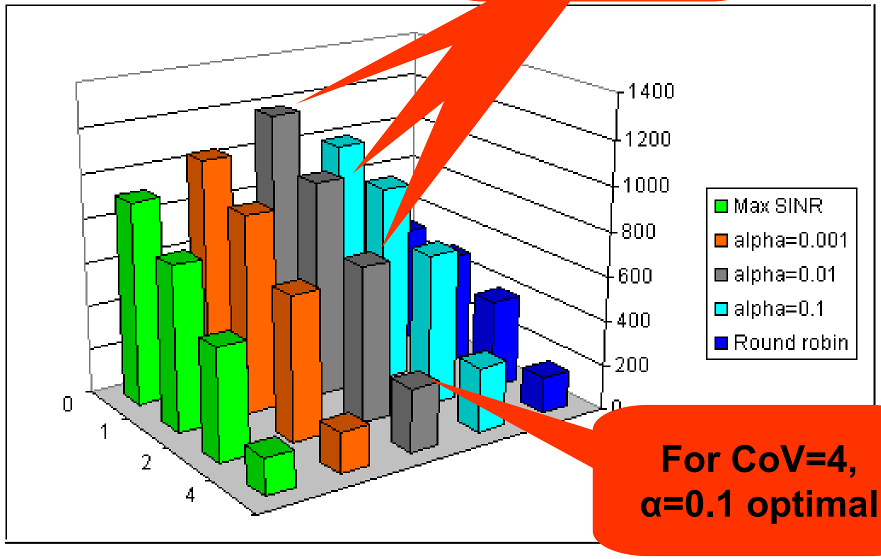
- **Sensitivity of the optimal settings of α, and ζ with respect to:**
  - Data traffic characteristics (file size distribution)
  - Multipath fading environment (users' speed)
  - Differences in the average signal strength (spatial distribution of users)
  - Traffic mix (data / video traffic)

- **Performance measure: maximum supportable cell load (Kbit/sec)**
  - Given QoS targets for data and video traffic

- **Observed sensitivity is minor**
  - Depends on QoS targets for both traffic types
  - α=0.01 and ζ=1 yields (near) optimal system performance

USE CASE: PACKET SCHEDULING

- Data only scenario
- Impact of file size distribution (CoV = 0,1,2,4)
- Maximum supportable cell load (Kbit/sec)
  - under given QoS targets for data traffic



For CoV=0, 1, 2, α=0.01 optimal

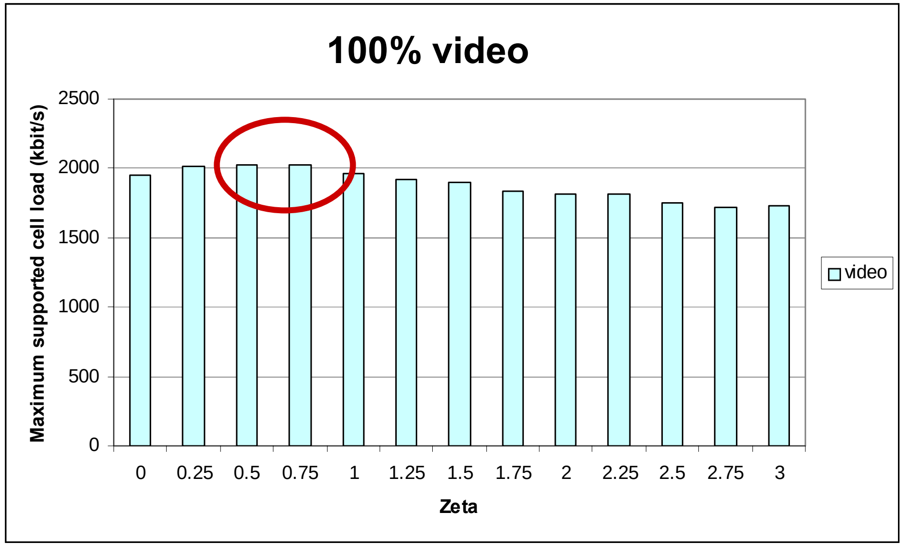
For CoV=4, α=0.1 optimal

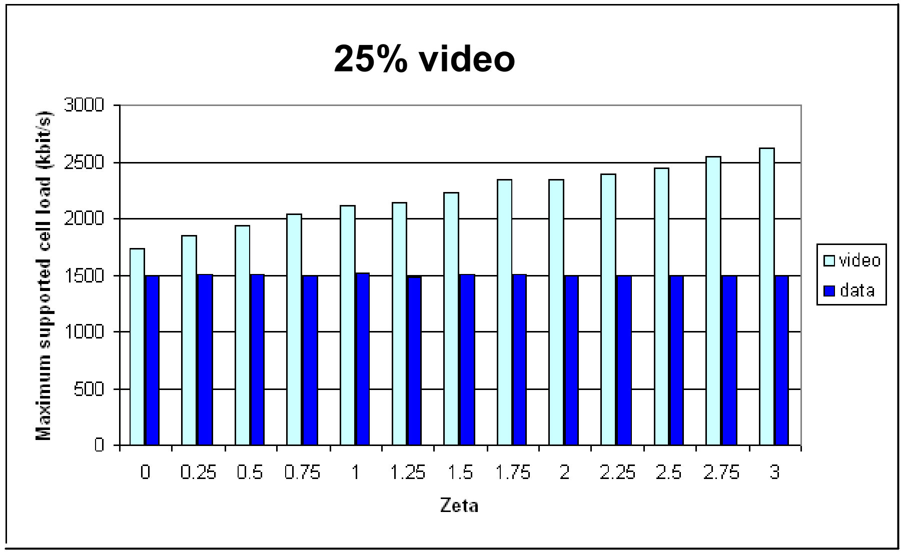
Impact of file size CoV on supportable cell load

USE CASE: PACKET SCHEDULING

- **Data / Video scenarios**
- **Impact of traffic mix**
- **Maximum supportable cell load (Kbit/sec)**
  - Given QoS constraints for video and data traffic

Results for alpha=0.01





- Zeta= 0.5 - 0.75 is the optimal setting
- Higher zeta: inefficient (less channel aware)

- Large zeta beneficial for video
- But data performance is limiting factor. Zeta = 0.75 still OK!

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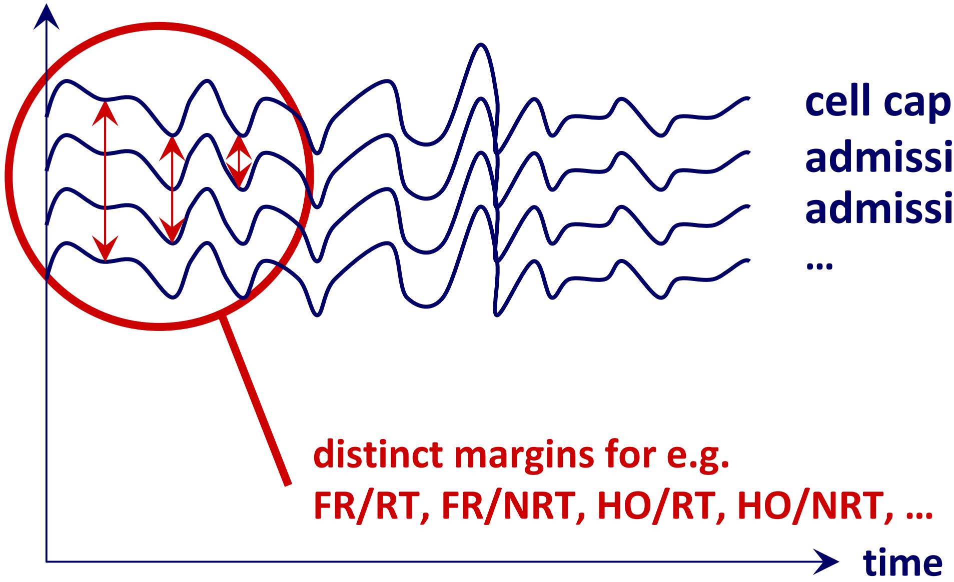
USE CASE: SELF-OPTIMISATION OF ADMISSION CONTROL

- Admission control
  - Key radio resource management mechanism
  - Objective is to admit as many calls as possible; prevent overload
    - such that service quality requirements can be satisfied
    - otherwise: call is blocked
  - Typical admission control rule: admit call iff $\rho(t) + \rho_{\text{new}} < c(t) - \text{margin}$
    - Margin accounts for handover calls, unexpected propagation effects, …

current load

load new call



USE CASE: SELF-OPTIMISATION OF ADMISSION CONTROL

- **Key challenges**
  - **How to determine cell capacity = non-trivial!!**
    - **c(*t*) varies over time and depends on e.g. traffic charac's**
  - **How to set the margins?**
    - **Too low means inadequate QoS**
    - **Too high means excessive blocking**
    - **Give sufficient preference to handover calls**
      - 'Sufficient' depends on degree of mobility, which may vary
    - **Give sufficient preference to real-time calls**
      - Little tolerance w.r.t. (temporary) QoS degradation
      - Optimal margin depends on occasional downgradability of non-real-time traffic
  - **Optimal margins depend on traffic- and system characteristics**
    - **Fraction HO calls (degree of mobility), traffic mix (RT/NRT traffic), propagation, …**

→ **Self-optimisation!!**

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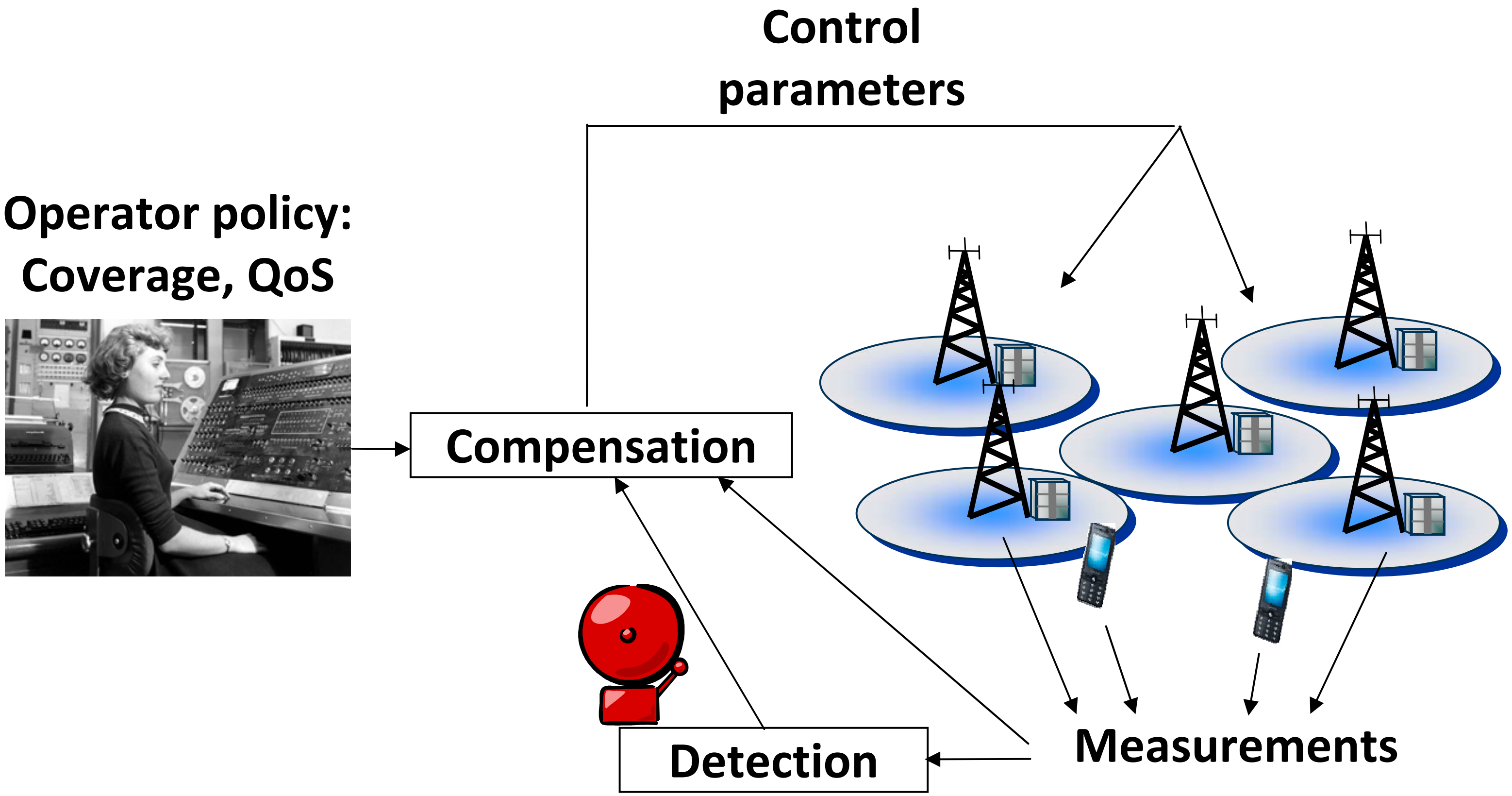
USE CASE: CELL OUTAGE MANAGEMENT

- **Self-healing use case**



Control parameters

Operator policy: Coverage, QoS

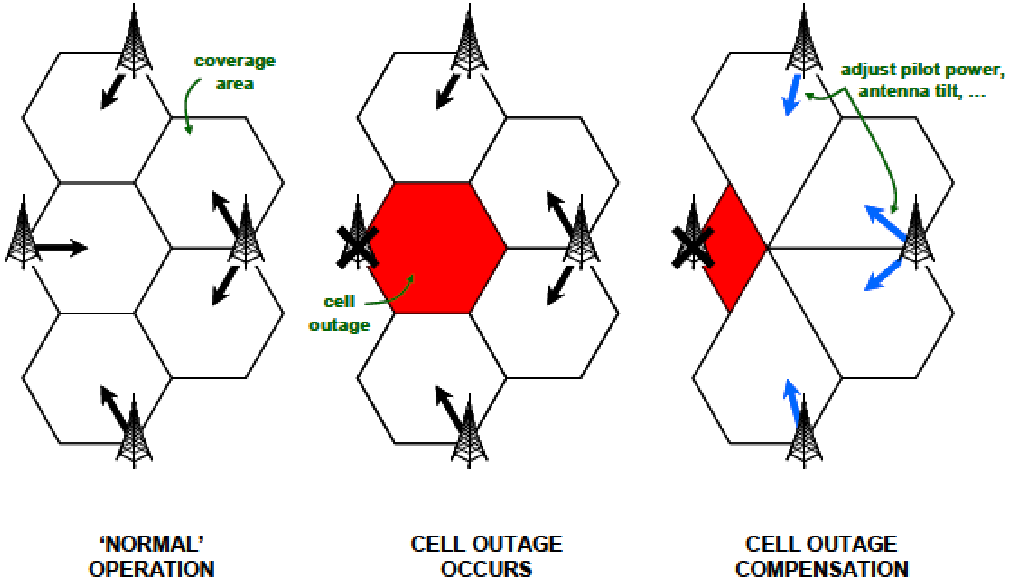
Compensation

Detection

Measurements

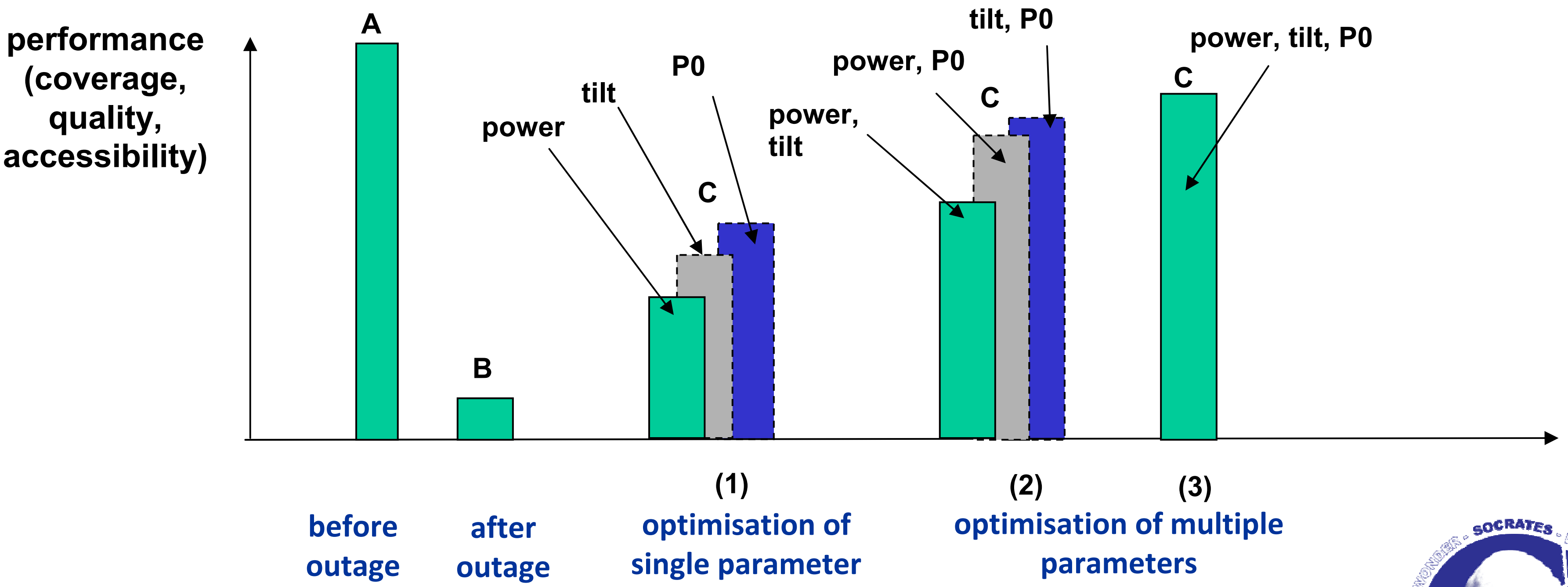
USE CASE: CELL OUTAGE MANAGEMENT

- **Cell outage detection**
  - What? Where?
  - …
- **Cell outage compensation**
  - Automatic compensation of failures
    - Optimise ‘regional’ coverage, capacity and/or quality
  - Control parameters
    - Power settings
    - Downtilt
    - Beamforming
    - Scheduler’s fairness parameter
    - Intra/inter-RAT handover parameters, load balancing
    - Neighbour cell lists



USE CASE: CELL OUTAGE MANAGEMENT

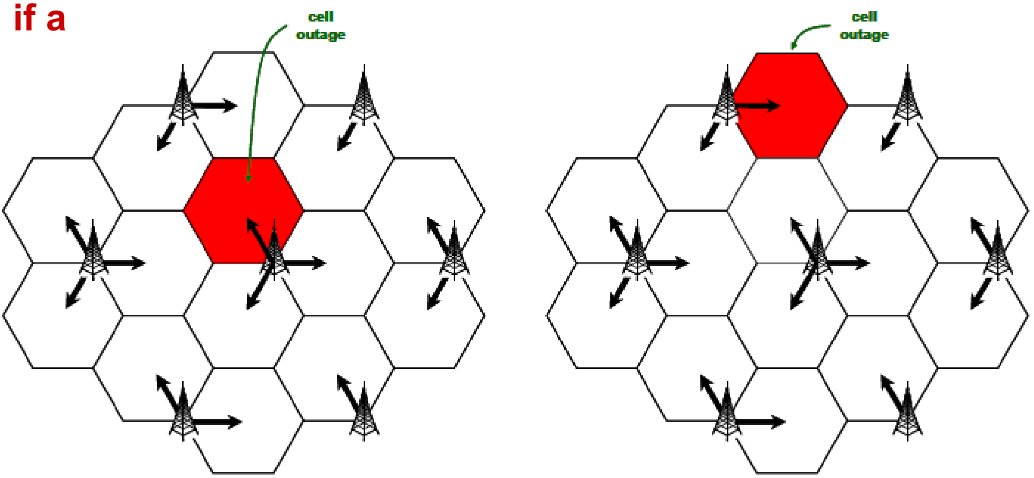
- **Cell outage compensation: impact control parameters**



USE CASE: CELL OUTAGE MANAGEMENT

- Scenarios for cell outage compensation
  - Impact of eNodeB density and load
    - More compensation potential in a dense capacity-driven network layout
  - Impact of service type
    - More compensation potential in an area with predominantly low-bandwidth service, e.g. VoIP telephony
  - Impact of outage location
    - More compensation potential if a cell/site outage occurs at the inner part of an LTE island
  - Also study impact of
    - user mobility, propagation aspects, spatial traffic distribution, UE class
- Controllability & observability
- Algorithm development
- Impact on 3GPP specifications


On-going work



CELL OUTAGE AT ISLAND'S CORE

CELL OUTAGE AT ISLAND'S EDGE

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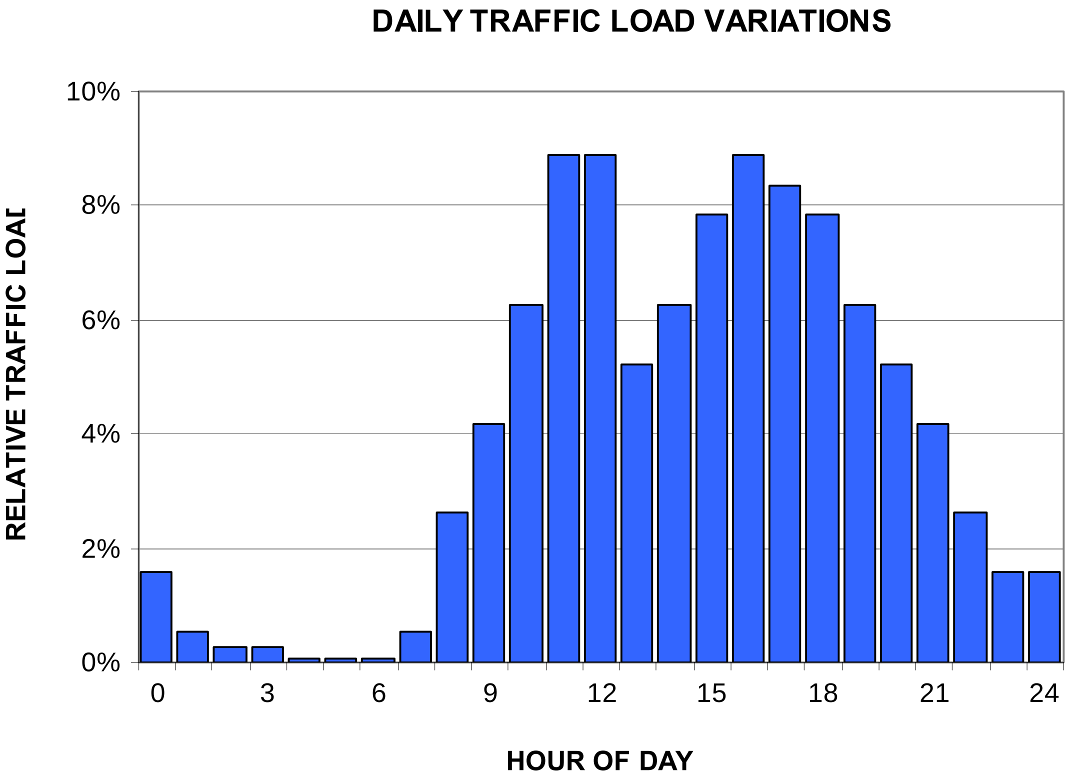
USE CASE: REDUCTION OF ENERGY CONSUMPTION

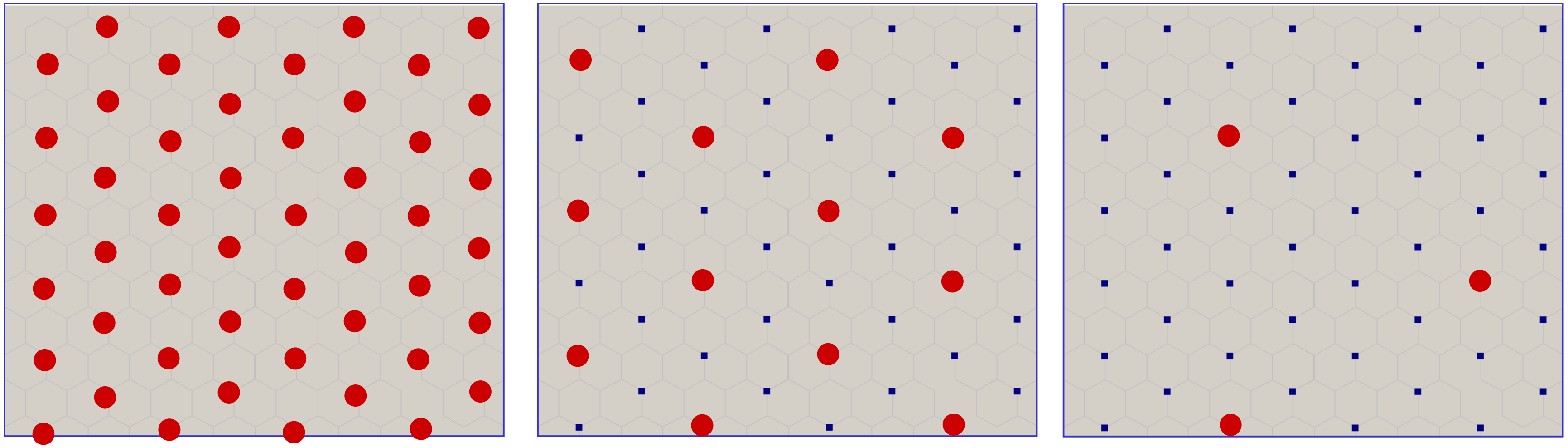
- Traffic load usually varies from hour to hour
- Networks are planned for peak hour performance

→ Over-capacity in off-peak hours can be turned off to save energy
  - Turn off sites
  - Turn off sectors
  - Turn of channel boards
  - Turn off carriers
  - Reduce transmit power
  - …



USE CASE: REDUCTION OF ENERGY CONSUMPTION

- Assessment of potential savings
  - Consider a data-only HSDPA network
  - Plan 48×3 hexagonal layout for coverage even when only 3 sites are active
  - Consider cases with $k \in \{48,36,24,12,9,6,3\}$ active sites



48 sites x 3 sectors

12 sites x 3 sectors

3 sites x 3 sectors

USE CASE: REDUCTION OF ENERGY CONSUMPTION

- **Assessment of potential savings**
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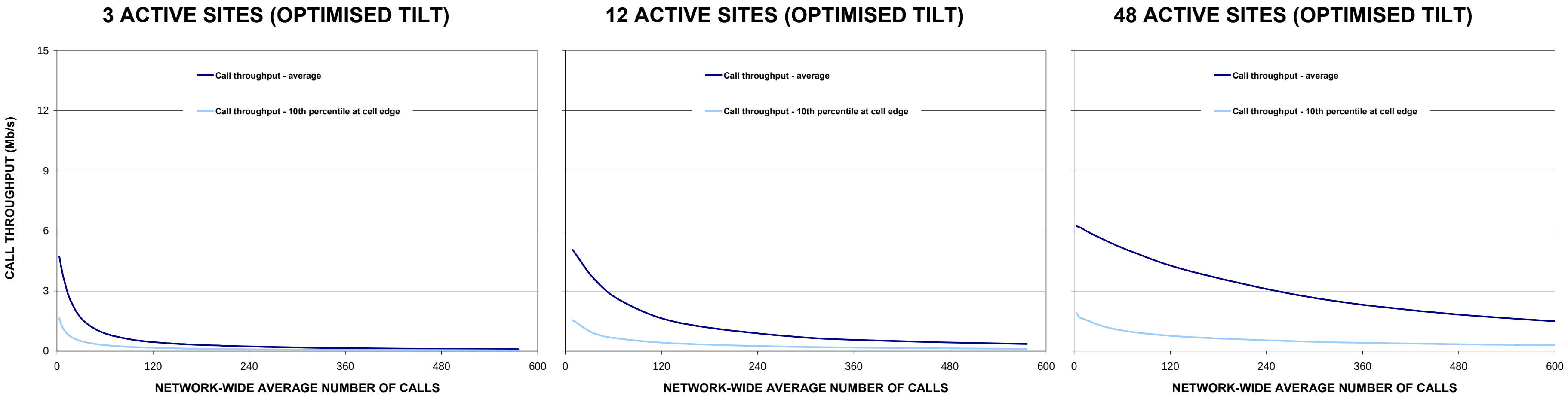
  - **Determine for each *k***
    - **the throughput performance versus the traffic load**



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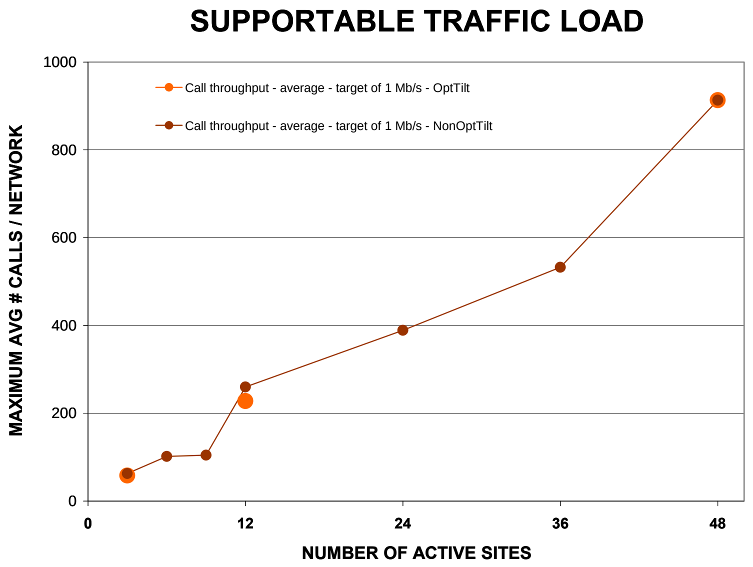
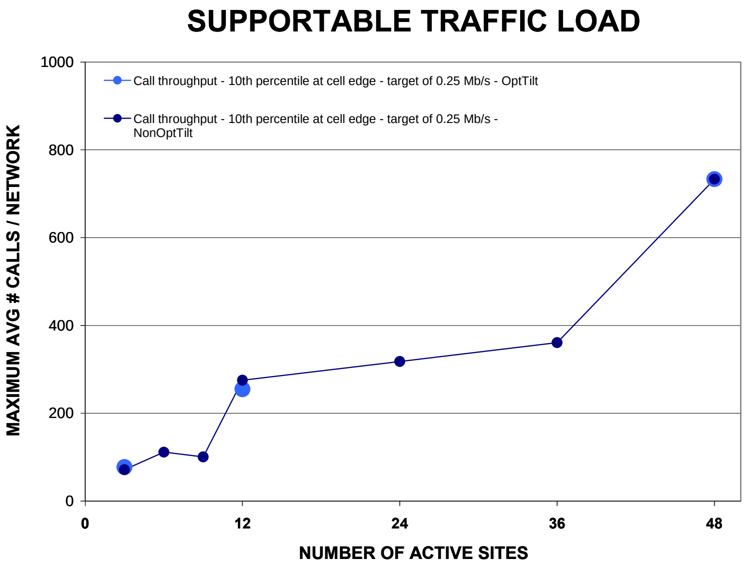
  - Determine for each k
    - the throughput performance versus the traffic load
    - the maximum supported traffic load such that performance target is met





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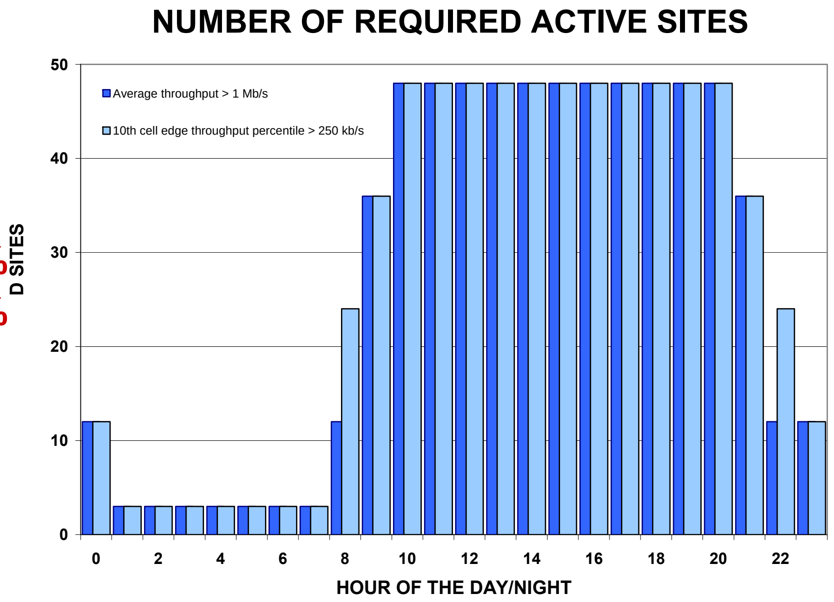
  - **Determine for each *k***
    - **the throughput performance versus the traffic load**
    - **the maximum supported traffic load such that performance target is met**
  - **Set peak hour traffic load equal to the max. supportable traffic load for *k* = 48**
  - **Derive for each hour of the day the min. *k* needed to support the corresponding traffic load with the set QoS target**
  - **Deduce potential energy reduction**
    - **average throughput → 41.9%**
    - **cell edge throughput perc'ile → 39.8%**

→ Self-optimisation!



USE CASE: REDUCTION OF ENERGY CONSUMPTION

On-going work

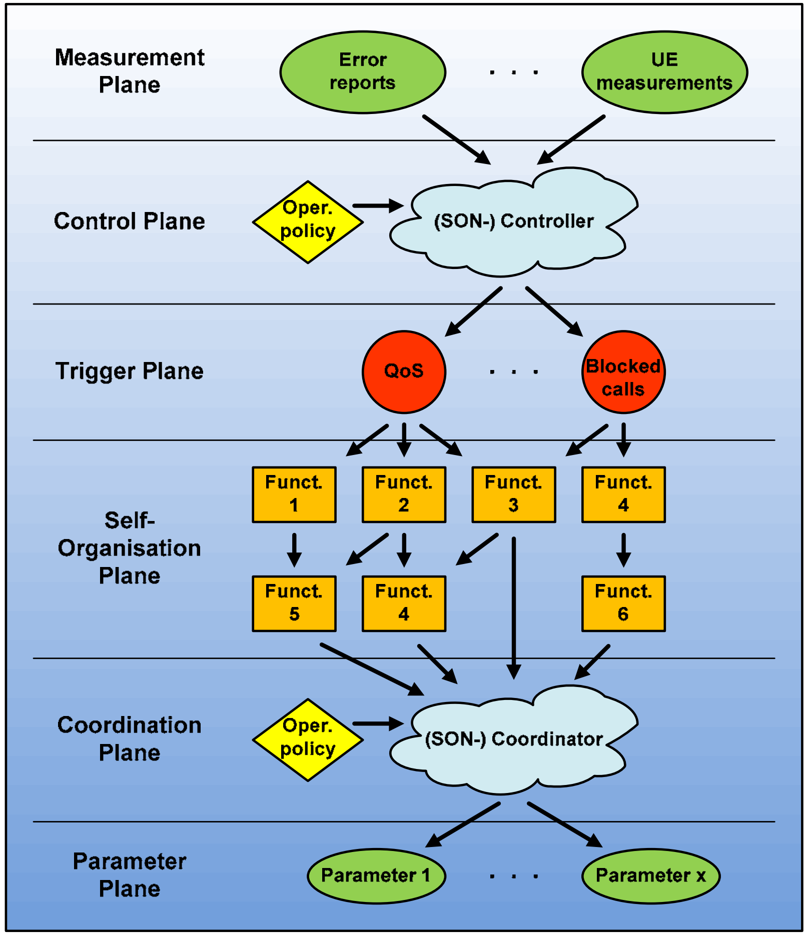
- **Algorithm development**
  - **Significant demonstrated potential**
  - **Develop algorithm to *turn off* sites in a dynamic setting**
    - **Appropriate measurement/filtering of carried traffic load per cell**
    - **Assess potential for surrounding sites to take over residual load**
    - **Optimise thresholds, window sizes, smoothing parameters**
    - **Take into account time/energy cost it takes to turn back on a site**
  - **Develop algorithm to *turn back on* sites in a dynamic setting**
    - **Appropriate measurement/filtering of carried traffic load in surrounding cells**
    - **Estimate traffic load in deactivated site's coverage area**
    - **Optimise thresholds, window sizes, smoothing parameters**
  - **Develop algorithm to automatically *adjust radio parameters* to match modified configurations**
    - **Pilot power, electrical tilt, Beamforming parameters, …**

OUTLINE

- Introduction
- Drivers
- Vision
- Expected gains
- Use cases
  - Packet scheduling
  - Admission control
  - Cell outage management
  - Reduction of energy consumption
- **Challenges**
- Approaches
- Who is who?
- Concluding remarks

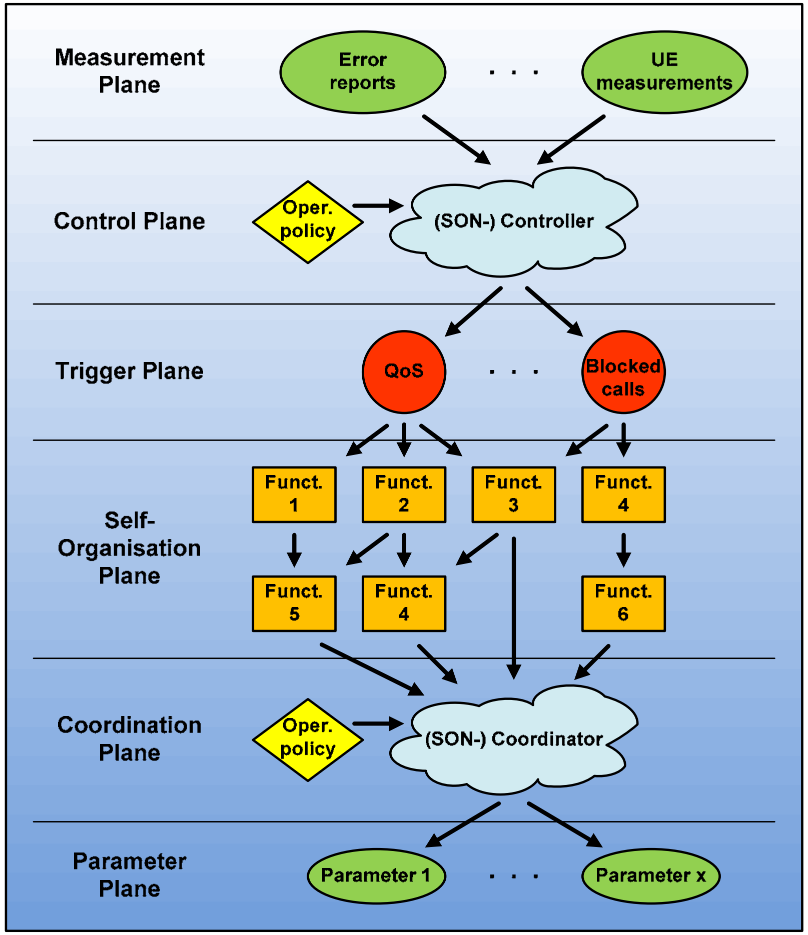
CHALLENGES

- Development of effective self-organisation methods imposes many challenges
  - Measurements
    - What data? What frequency? Tuned to urgency?
    - Trade-off: signalling costs vs achieved performance
    - Appropriate processing to determine 'network state'
    - Detection/handling of erroneous/ malicious reports
  - Effectiveness of self-organisation
    - Multi-objective optimisation
    - Intricate parameter dependencies
      - oscillations!
    - Centralised vs distributed control
    - Convergence time of self-opt. algorithms



CHALLENGES

- **Development of effective self-organisation methods imposes many challenges**
  - **Dealing with delayed feedback**
    - **Feedback upon control actions is not immediate**
    - **Effects of control decisions or due to natural variations**
  - **Reliability**
    - **Actions must be reliable**
    - **No human sanity checks or revision of actions**
    - **Operator must trust the system when giving up direct control**
      - Gradual introduction



Measurement Plane

Error reports . . . UE measurements

Control Plane

Oper. policy

(SON-) Controller

Trigger Plane

QoS . . . Blocked calls

Self-Organisation Plane

Funct. 1 | Funct. 2 | Funct. 3 | Funct. 4

Funct. 5 | Funct. 4 | Funct. 6

Coordination Plane

Oper. policy

(SON-) Coordinator

Parameter Plane

Parameter 1 . . . Parameter x

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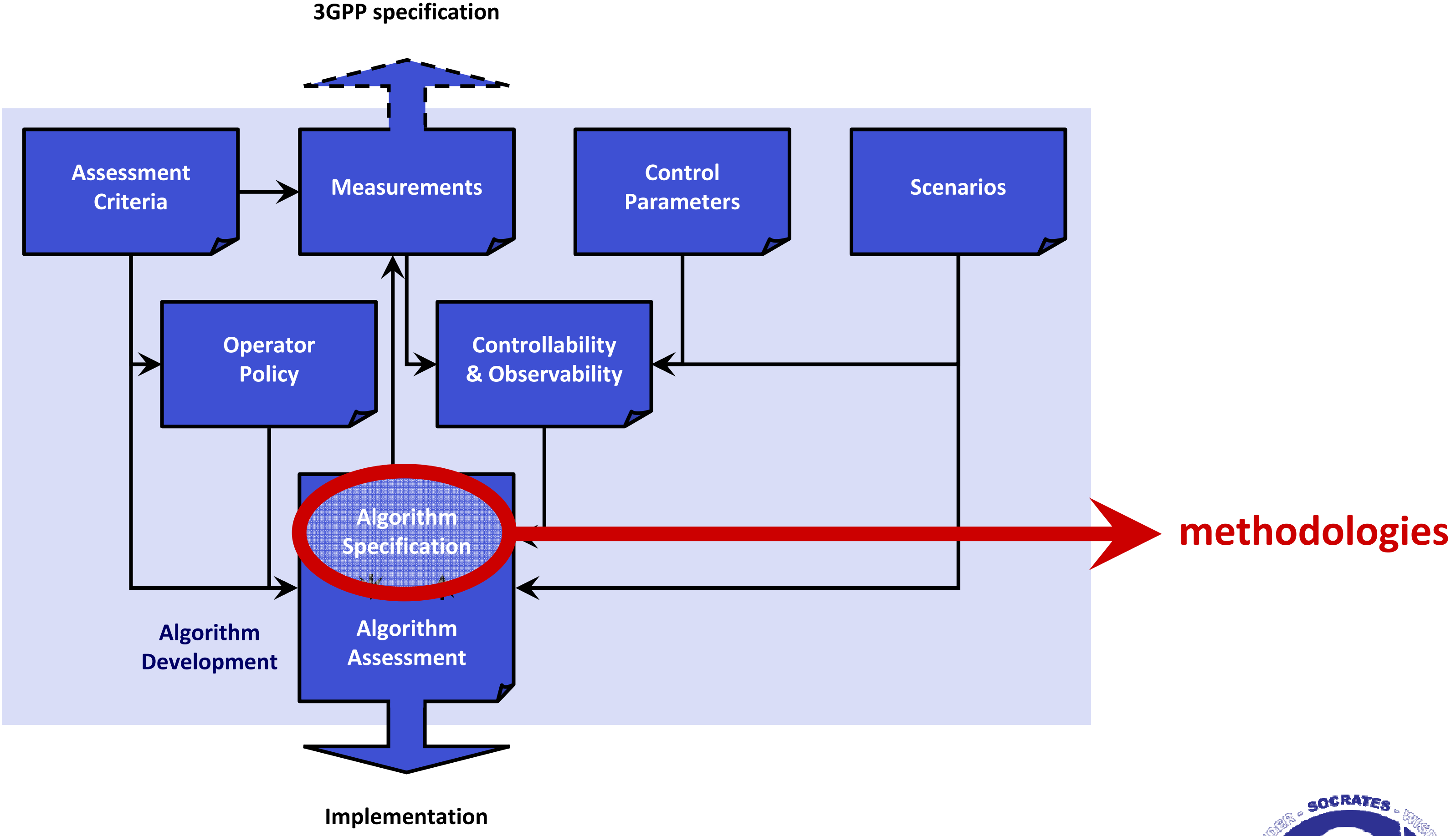
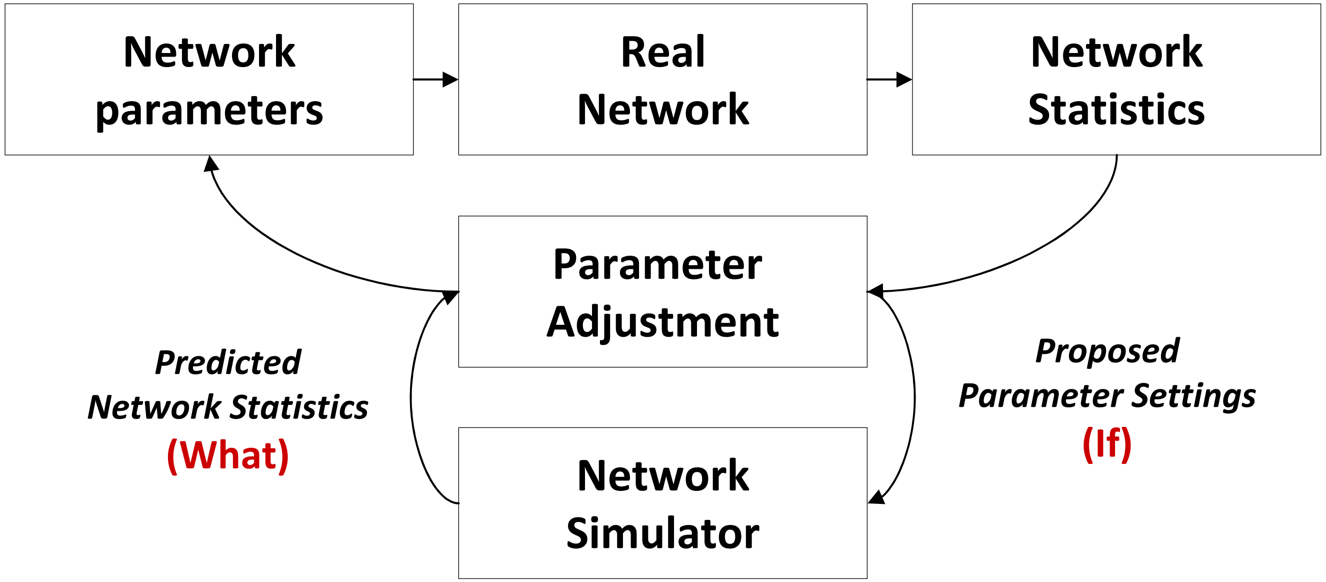
SELF-OPTIMISATION APPROACHES

- **Generic approach**



SELF-OPTIMISATION APPROACHES

- **Approach 1: Off-line 'simulation-based optimisation'**
  - ***Optimisation Algorithm*** **exploits a** ***Network Simulator*** **for 'what if' analyses, i.e. test potential parameter adjustments before application in the** ***Real Network***
    - **Equivalent to current approach to off-line optimisation**
    - **Specific problem imposes requirements on speed and accuracy**



Network parameters

Real Network

Network Statistics

Parameter Adjustment

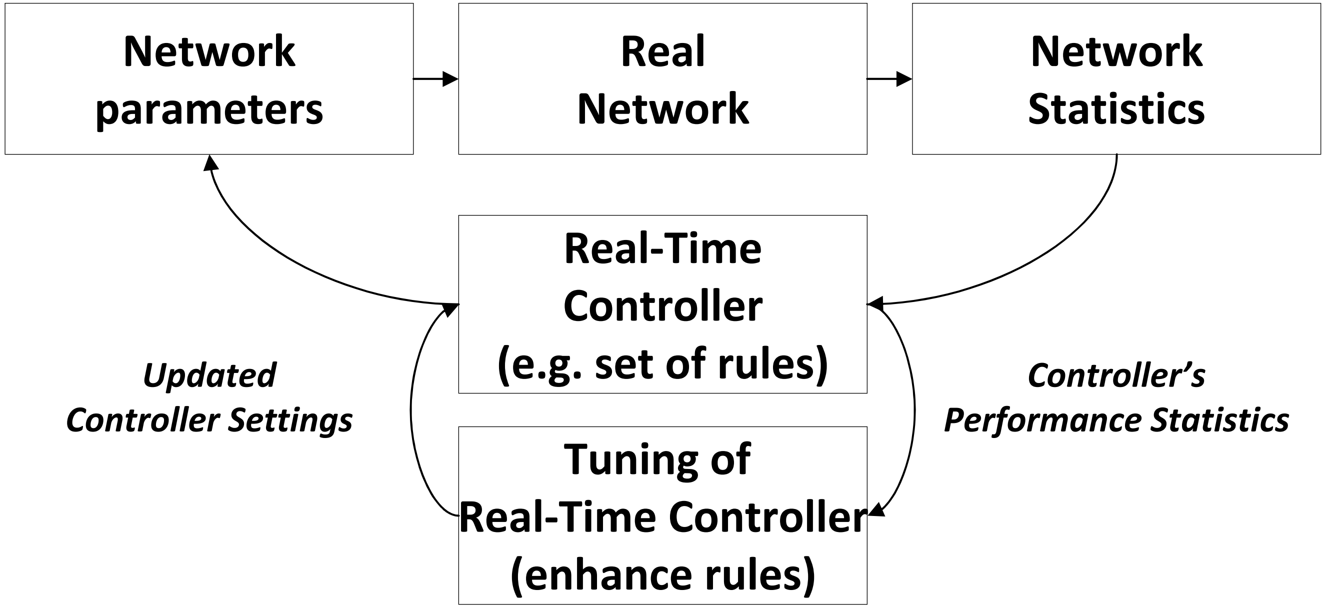
Network Simulator

Predicted Network Statistics
(What)

Proposed Parameter Settings
(If)

SELF-OPTIMISATION APPROACHES

- **Approach 2: ‘Off-line optimised real-time controller’**
  - ***Real-Time Controller* rapidly responds to changes**
    - **E.g. ‘rule-based’ optimisation**
  - **Periodic off-line tuning of *Real-Time Controller***
    - **E.g. adaptation and/or extension of rules**



Network parameters

Real Network

Network Statistics

Real-Time Controller (e.g. set of rules)

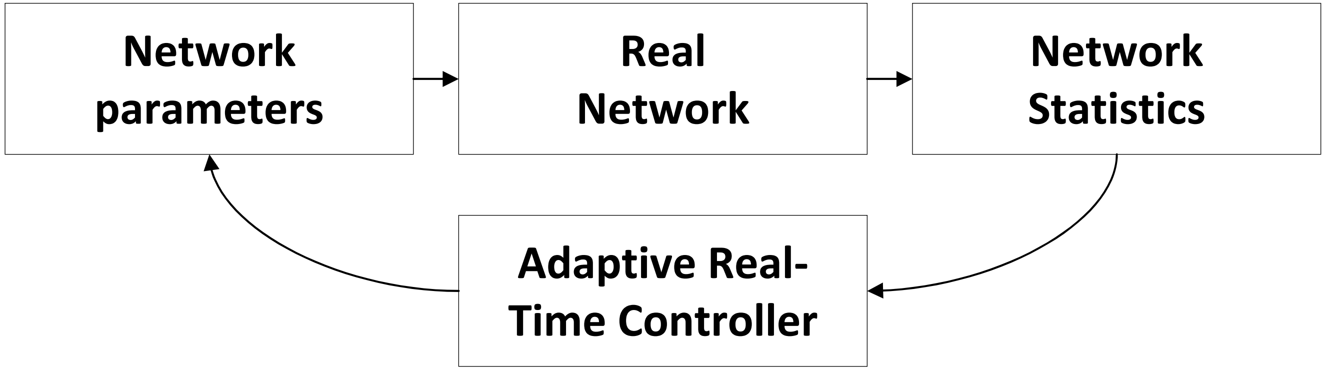
Tuning of Real-Time Controller (enhance rules)

Updated Controller Settings

Controller’s Performance Statistics

SELF-OPTIMISATION APPROACHES

- **Approach 3: ‘On-line optimised real-time controller’**
  - **Periodic/continuous on-line tuning of *Real-Time Controller***
    - **Example admission control with Reinforcement Learning**
      - Reference CAC scheme with an RL-based self-optimisation layer on top, optimising the CAC parameters
      - Integrated RL-based CAC scheme, directly optimising the mapping of system state to admission/rejection decision



- **Involves initialisation and training phase with randomised actions**
- **Inherent degree of ‘black box character’ limits ‘trustworthiness’**

SELF-ORGANISATION METHODOLOGIES

- **Non-exhautive list of potentially applicable optimisation techniques**

fuzzy Q-learning

neural networks

iterative learning control

neural swarming

neuro-evolution of augmenting topologies

open-loop control

genetic programming

fuzzy logic

random search

branch & bound

automatic control

reinforcement learning

metamodels

perturbation analysis

clique detection

non-gradient based methods

Markov decision processes

sample path

ordinal optimisation

gradient based methods

model predictive control

expert systems

proportional-integral-derivative control

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CONCLUDING REMARKS

- Self-organisation key approach to …
  - … reduce O/CAPEX
  - … cost-effective provisioning of high-quality services
  - … reduce time-to-market of new features, services
- Key components
  - Self-configuration
  - Self-optimisation
  - Self-healing
- Exciting challenges
  - Effectiveness, reliability, stability
  - Measurements, interfaces, protocols, architectures
- Involved parties/projects
  - NGMN, 3GPP, GANDALF, E3, SOCRATES, …