Addressing 5G Network Management Challenges with Machine Learning

23. ITG Fachtagung Mobilkommunikation, 17.5.2018

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## 5G Network Management

### Addressing the challenges

<table>
<thead>
<tr>
<th>Ultra Dense Small Cells</th>
<th>Cloudified RAN &amp; Core</th>
<th>Multi-connectivity (MC)</th>
<th>URLLC network service</th>
<th>Multi-service Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution</td>
<td>Centralization</td>
<td>Multi-RAT / layer</td>
<td>Low latency radio, edge cloud</td>
<td>Slices</td>
</tr>
</tbody>
</table>

- **Flexible VNF re-location / re-configuration**
- **Distributed decisions; Management hierarchy / aggregation**
- **Combined management of physical / virtualized infrastructure**
- **MC-aware, management incl. aggregation of PM/FM data**
- **NM data resolution; prognostic diagnosis; combined network resilience & self-healing**
- **Intra- / inter-slice management; Separation (& sharing) of knowledge; Embedded analytics**

**“Hybrid” NM**
“Self-organization is a process where the organization (constraint, redundancy) of a system spontaneously increases, i.e., without this increase being controlled by the environment or an encompassing or otherwise external system.” (F. Heylighen, Principia Cybernetica Web, 1997)
Cognition

„Cognitive Functions“: inputs → ML algorithm / rules → outputs
• Gaining *machine-level insights* from data

**Combining** machine-level insights with human insights
• Closed-loop Cognitive Functions (for specific, frequent tasks)
• Linking to human-level workflows through open-loop functions (for other, more complex tasks)

Cognition is „the brain“ of the future mobile network business (design, build/commission, operate, de-commission)

Building knowledge in silos is not sufficient
→ **sharing** knowledge inside an operational domain and across different, related areas
Machines vs. Humans

Fast number-crunching (e.g., multi-variate KPI data processing)
Keeping a lot of historical information
Executing lots of concurrent low-level tasks / decisions, etc.

**Machine overriding human** (potential erroneous actions / mis-configuration, easy to detect with the machine-level, fast, concurrent processing)

**Human overriding machine** (still limited machine intelligence and limited / erroneous instrumentation, easy to detect with human intuition)

Using intuition to make complex decisions under uncertainty (e.g., “low level” root cause diagnosis; expressing high-level targets and tradeoffs)
Machines vs. Humans

Challenges wrt. Machine intelligence

• Data uncertainty / incompleteness / volatility / variability:
  - Cell level data (PM, FM, CM) provides only incomplete, system-internal view; mostly treated in isolation
  - Significant changes over time (new NE/cells, new SW releases, …), different deployments
  - System-external information and human operator knowledge is decoupled

• Knowledge transfer from human to machine domain
  - Lack of systematic human-level knowledge management

• Technical applicability
  - Many different AI approaches with different capabilities / constraints
  - Considering analogies in other domains, e.g., rule generation in coordination / verification compared to firewall rules coming from intrusion detection
5G Network Management

- IoT support
- D2D
- Self-backhauling
- Virtualized Network Functions
- Ultra-dense small cells
- Low latency
- Multi-hop
- Low cost
- High reliability
- Location information
- Low power consumption

Cognitive Network Mgmt. System (multi-vendor, multi-tenant)

- Optimization
- Troubleshooting / Healing
- Configuration

Analytics
Policy

(Trained) telco-centric knowledge models & context

network data
network scenarios
5G NM: functional architecture

Network Slice Mgmt.

- Preparation, LCM / (re-)configuration
- Anomaly Detection → Diagnosis → Healing action
- Scaling

Load balancing / traffic steering
- Scaling in/out, down/up

Coverage and Capacity Optimization

Mobility robustness (MRO)
- Anomaly Detection → Diagnosis → Healing

Neighbour relationship setup (ANR)

Resource ID allocation (beam/cell ID/RS)

OAM connectivity / interface setup

Radio resources (beams, cells): PNFs

Cloud resources

Communication Service Mgmt. (eMBB, mMTC, cMTC)

Policy

- Objectives / Intent
- Management Policies
- Coordination

Cognitive NM functions

- (Big) data acquisition and distribution
- MDT / location
- Machine Learning
- Knowledge Sharing / Isolation
- Verification
- Machine Learning

Analytics

- Engine
- Knowledge Sharing / Isolation
- Verification
- Machine Learning
- (Big) data acquisition and distribution
- MDT / location
Different 5G use case requirements \(\rightarrow\) slice characteristics \(\rightarrow\) set of cognitive functions

<table>
<thead>
<tr>
<th>Use Case</th>
<th>SMF/Control Plane Capacity</th>
<th>Mobility Frequency</th>
<th>UPF/Forwarding Capacity</th>
<th>Latency Challenge</th>
<th>Resiliency need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Meters</td>
<td>MEDIUM</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
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<tr>
<td>Car to Car</td>
<td>HIGH</td>
<td>HIGH</td>
<td>LOW</td>
<td>HIGH</td>
<td>HIGH</td>
</tr>
<tr>
<td>Fixed Wireless</td>
<td>LOW</td>
<td>LOW/None</td>
<td>Ultra HIGH</td>
<td>MEDIUM</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Consumer Mobility</td>
<td>MEDIUM</td>
<td>HIGH</td>
<td>MEDIUM</td>
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</tr>
<tr>
<td>Industrial IoT</td>
<td>LOW</td>
<td>LOW</td>
<td>HIGH</td>
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*SMF: Session Management Function  UPF: User Plane Function*
Different 5G use case requirements → slice characteristics → set of cognitive functions

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<tr>
<td>mMTC</td>
<td>MEDIUM</td>
<td>LOW</td>
<td>LOW</td>
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<tr>
<td>cMTC / high mobility</td>
<td>HIGH</td>
<td>HIGH</td>
<td>LOW</td>
<td>HIGH</td>
<td>HIGH</td>
</tr>
<tr>
<td>eMBB / no mobility</td>
<td>LOW</td>
<td>LOW/None</td>
<td>Ultra HIGH</td>
<td>MEDIUM</td>
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<td>MEDIUM</td>
<td>HIGH</td>
<td>MEDIUM</td>
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<tr>
<td>cMTC / low mobility</td>
<td>LOW</td>
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<td>HIGH</td>
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Different 5G use case requirements → slice characteristics → set of cognitive functions

### Radio vs. Cloud resources

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<tr>
<td>mMTC</td>
<td>→ Cloud</td>
<td>→ Radio</td>
<td>→ Radio &amp; (Edge) Cloud</td>
<td>→ Radio: Multi-cell coord. &amp; connectivity</td>
<td></td>
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<tr>
<td>cMTC / high mobility</td>
<td></td>
<td></td>
<td></td>
<td>→ Cloud: Edge Cloud, VNF resiliency</td>
<td></td>
</tr>
<tr>
<td>eMBB / no mobility</td>
<td></td>
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Cognitive NM functions: inputs → ML algorithm / rules → outputs

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<th>Cognitive NM Function</th>
<th>Examples for applicable ML algorithm</th>
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<tr>
<td>Load balancing / traffic steering</td>
<td>Metaheuristics (PSO*) / decision tree</td>
</tr>
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<td>Coverage and Capacity Optimization</td>
<td>Reinforcement learning (QL*)</td>
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<td>Mobility robustness (MRO)</td>
<td>Reinforcement learning (QL*)</td>
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<td>Scaling in/out, down/up</td>
<td>Reinforcement learning; Graph Neural Nets</td>
</tr>
<tr>
<td>Anomaly Detection → Diagnosis → Healing</td>
<td>Topic Modeling → MLN* → Utility Theory</td>
</tr>
<tr>
<td>Network Function Chaining</td>
<td>Metaheuristics (genetic algorithms)</td>
</tr>
<tr>
<td>LCM / (re-)configuration, (re-)placement</td>
<td>Metaheuristics (harmony search)</td>
</tr>
<tr>
<td>Neighbour relationship setup (ANR)</td>
<td>n/a (rules)</td>
</tr>
<tr>
<td>Resource ID allocation (beam/cell ID/RS)</td>
<td>Unsupervised learning (clustering)</td>
</tr>
<tr>
<td>OAM connectivity / interface setup</td>
<td>n/a (rules)</td>
</tr>
</tbody>
</table>

* PSO: Particle Swarm Optimization, QL: Q(uality) Learning, MLN: Markov Logic Networks
Example: anomaly detection and diagnosis – overview

- OSS counters
- KPIs
- Profiles
- Anomaly values
- Contexts
- Anomaly detection/aggregation
- Pattern clusters
- Anomaly patterns
- Labeling
- Augmented learning
- Trend changes
- Root cause analysis

- Example: anomaly detection and diagnosis – overview
Network Weather Report
Overview of network state and diagnosis in spatial and temporal context
Anomaly detection procedure
Context-aware learning of normal states, measuring anomalousness in diurnal behavior and correlation
Augmented diagnosis
Synergetic exploitation of human-machine capabilities for fast and efficient analysis

rthink
interpretation of the data

loop

restructure
structured view of the data
Augmented diagnosis

1. Labels a few examples of the major expected anomaly groups

2. Creates a clustering taking the labeled points into account

3. Expands and refines the labeling:
   - Labels the previously unlabeled anomalies in the expected groups
   - Labels the anomalies in the unexpected groups

4. Any newly arriving anomalies can be automatically labeled with this information
Use Case Example from a Major Operator

- Augmented learning \(\rightarrow\) new cluster of intra- and inter-eNB Handover problems (distinct classes of anomalies that had not been discovered / analyzed yet)

Anomaly pattern

New identified problem cluster \(\rightarrow\) new „golden configuration“
Addressing 5G Network Management Challenges with Machine Learning

Conclusions

• 5G Network complexity (ultra dense, cloudified, multi-service / -tenant) imposes new operability challenges
  • Functional:
    • per service- / tenant- instrumentation and dynamic operation (multiplicity of varying virtual network configurations)
    • data: higher resolution of measurements; new external sources / context
    • higher degree of autonomy in management
  • Architectural:
    • new building blocks related to slicing management
    • higher degree of distribution, cooperation / coordination and abstraction
• Cognitive NM functions
  • Shield the complexity of physical and virtual network functions from higher layers
    → balancing human and machine decision making
  • Are intra- / inter-slice-aware; sets of CFs are defined per slice type
  • Enable the management of diverse service types in diverse network scenarios
Addressing 5G Network Management Challenges with Machine Learning

Conclusions

• **Machine Learning: key enabler to realized Cognitive NM functions → approach:**
  • Matching of key use case characteristics with technology capabilities → selection
  • Anomaly Detection / Diagnosis
    • Holistic PM/FM/CM analysis: leverage the potential of the data, by comprehensive analysis, combine network data with context data → high quality detection + basic diagnosis (unsupervised learning)
    • Motivate Network Operations Experts to combine their knowledge with the machine-level → (semi-)supervised learning (augmented diagnosis)

• **Research challenges**
  • 5G URLLC management: instrumentation, prognostic diagnosis
  • Cognitive Function placement
  • Slice management (incl. knowledge sharing & isolation)
  • Management of interworking legacy net(s), 5G (private / public)
### SON + ML = Cognitive Network Management functions

<table>
<thead>
<tr>
<th>Input data</th>
<th>SON</th>
<th>Cognitive Network Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structured data; rel. Low spatial and temporal resolution</td>
<td>Structured and unstructured data; both low and high spatial and temporal resolution (real-time, location-annotated) → <strong>exploit available data to the max; be flexible / robust wrt. the data availability / quality</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Simple feature extraction (fixed thresholds on raw KPIs)</th>
<th>(Pre-processing of unstructured data) Advanced feature extraction (training based on KPI distributions) → <strong>no configuration of thresholds, deploy → train → operate</strong></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Static: fixed algorithm / ruleset (adaptation time cycle: NE SW update interval: ~months)</th>
<th>Dynamic: probabilistic reasoning &amp; learning (adaptation time cycle: rule update interval: ~hours) → <strong>fast, autonomic adaptation to specific deployment situation</strong></th>
</tr>
</thead>
</table>

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<tr>
<th>Actions</th>
<th>Single step, simple actions (sometimes circumventing the problem rather than solving it, e.g., cell resets)</th>
<th>Multiple step action <strong>planning</strong>, considering utility; smarter, fine granular actions → <strong>smarter automated actions taking into account context (cost)</strong></th>
</tr>
</thead>
</table>

<table>
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<tr>
<th>Management</th>
<th>Technical policies</th>
<th>Business-level policies (**operator objectives / “intent”) → automatically derived technical policies; high-level feedback for <strong>trust</strong>-building (verification)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Use cases</th>
<th>Simple „replacing“ (OPEX-improving, e.g., ANR) and „new“ (quality-improving, e.g., MRO/MLB) features</th>
<th>Also complex „new“ (e.g., Cell Anomaly Detection), „Integrating“ (Coordination, Verification) and „Supporting“ (e.g., Cell Degradation Diagnosis, tightly integrated with human-level workflows) features → <strong>covering a wide(r) range of use cases</strong></th>
</tr>
</thead>
</table>

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## Example: Cell anomaly detection and diagnosis – ML Algorithms

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<tr>
<th>Cognitive NM Function</th>
<th>Examples for applicable ML algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input selection</td>
<td>Genetic algorithms, PCA</td>
</tr>
<tr>
<td>Multi-dimensional non-normally distributed profiling</td>
<td>Clustering: k-NN, SOM, GNG</td>
</tr>
<tr>
<td>Anomaly level calculation</td>
<td>Multi-dimensional probabilistic distributions</td>
</tr>
<tr>
<td>Anomaly event aggregation</td>
<td>DBSCAN</td>
</tr>
<tr>
<td>Diagnosis</td>
<td>Decision theory, rulebases, different distance measures: Mahalanobis, Kullback-Leibler divergence or Hellinger</td>
</tr>
<tr>
<td>Augmented learning</td>
<td>Active learning, DBSCAN, k-NN</td>
</tr>
</tbody>
</table>