SON Management Based on Weighted Objectives and Combined SON Function Models

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***Abstract*—The instrumentation of Self-Organising Network (SON) Functions in such way that they contribute to the operational objectives defined by a wireless network operator is a complex task. In order to enable automation of this configuration, we previously described the concept of a SON Objective Manager (SOM) which determines the best configuration based on conditional, ranked objectives and SON Function models describing the Key Performance Indicators (KPIs) optimised by some configuration. However, the simplicity of the models and the complexity of the design-time inference may limit the applicability of the initial concept. In this paper, we present an extended and enhanced run-time SOM with more expressive input models, namely, context-dependent, weighted operator objectives allowing a better trade-off and SON Function models defining the possible values of KPIs for some configuration. These improvements together allow for a broader application of the concept.**

***Keywords*—self-organising networks; network management; objective-based management**

I. Introduction

Self-Organising Network (SON) Function algorithms are closed control loops aiming at the autonomous configuration, optimisation and troubleshooting of Network Configuration Parameters (NCPs) in mobile wireless networks [1], with the goal to improve the network Key Performance Indicators (KPIs) such as Dropped Call Rate (DCR) and Handover Success Rate (HOSR) at lower operational cost. Each SON Function itself can be configured through SON Function Configuration Parameters (SCPs), e.g., step size or thresholds, and the corresponding SON Function Configuration Parameter Values (SCVs), deployed as SCV Sets. An SCV Set contains exactly one SCV per SCP, for all SCPs a SON Function has. By modifying its SCVs, the behaviour of a SON Function can be influenced regarding its impact on NCPs and in turn the network KPIs [2]. The goal of SON management is to instrument the SON Functions such that they jointly achieve target values of the KPIs defined by the mobile network operator. The KPI targets may depend on the operational context, e.g., cell type or location, or the time of the day.

In current SON systems, the SCVs are adjusted manually by human operators. Due to the required effort usually a default SCV Set, provided by the SON Function manufacturer, is applied to each SON Function. This may lead to a non-optimal operation of the SON with respect to the KPI targets, since the default SCV Sets do not adapt to (changing) operational context. Furthermore, as a SON Function in general is delivered as a black-box, the determination of a dedicated SCV Set for a set of KPI targets is non-trivial for the operator since it is not possible to accurately estimate the behaviour of a SON Function for some SCV Set.

In [3] a concept for a SON Objective Manager (SOM) is described that automatically selects the best SCV Sets for the SON Functions with respect to the operator objectives. It uses two types of models as input: first, a SON Function model for each SON Function defining the KPIs that are optimised or deteriorated by a specific SCV Set, and second, an Objective model describing the operator's context-specific and prioritised KPI targets. The SOM generates a SON Policy whose execution deploys those SCV Sets to the SON Functions that optimise the highest prioritised KPI in the current context. Despite being an important step towards automated network management, this SOM approach has three shortcomings. First, the SON Function model can only describe the maximisation, minimisation, or neutrality of a KPI value but not that a specific SCV Set keeps the KPI value within some range. The same applies for the Objective model. Second, the ranking of the KPI targets through operator defined priorities does not allow a trade-off between the objectives if not all KPI targets can be satisfied. Third, the design-time computation of the SON Policy is computationally very complex due to an exponential growth of the considered state space.

To overcome the shortcomings from [3] this paper presents an improved approach. First, the expressiveness of the SON Function model is enhanced such that a certain SCV Set influences a KPI by maximisation, minimisation, neutrality, or by keeping it within a specific interval, e.g., DCR $\leq 2\%$. Furthermore, the Objective model allows to express concrete value ranges for the KPIs that the SON should satisfy. With this differentiation, the SOM is enabled to better adapt the SCV Sets to the operator objectives and can identify conflicts between different SON Function configurations. Second, the KPI targets are weighted instead of ranked in the Objective model, which allows to select the best SCV Set for a weighted satisfaction of the KPI targets. Third, the SOM approach presented in this paper does not create a SON Policy but performs its computation at *run-time* and directly determines the SCV Sets to be deployed. Hence, it is not necessary to consider the exponentially huge state space of operational contexts that the SON might encounter but solely the actual current context. In summary, the presented approach clearly allows more complex models compared to [3] that reflect the requirements on KPI target setting in real systems.

DOI: 10.1109/ISWCS.2014.6933337

II. SON-ENABLED NETWORK MODEL

This section presents the formalisation of a SON-enabled mobile network, illustrated in (1)-(3). F is the set of all SON Functions, e.g., Mobility Load Balancing (MLB), Mobility Robustness Optimisation (MRO), Coverage and Capacity Optimisation (CCO). For each SON Function $f \in F$, a set S^f is given containing different SCV Sets. An SCV Set s^f is a tuple of SCVs $v_1^{s^f}, v_2^{s^f}, \ldots$ for the input parameters of f, i.e., the SCPs. The performance of a mobile network is monitored through a set of system KPIs K, e.g., DCR, HOSR, and Load. Thereby, it is assumed that each KPI $k \in K$ may have a different value range $\mathrm{Dom}(k) \subseteq \mathbb{R}$, e.g., $\mathrm{Dom}(\mathrm{DCR}) = [0, 1]$.

$$F = \{f_1, f_2, \ldots, f_{|F|}\} \tag{1}$$

$$S^f = \left\{s_1^f, s_2^f, \ldots, s_{|S^f|}^f\right\} \tag{2}$$

$$K = \{k_1, k_2, \ldots, k_{|K|}\} \tag{3}$$

Furthermore, in order to simplify the illustration of the extended SOM concept, it is assumed that all SON Functions have a cell-scope, i.e., for each single cell in the network, there is an instance of each SON Function adapting the network configuration parameters of solely that cell. Accordingly, the objectives in the objective model are evaluated in the context of single cells. This assumption allows to configure the SON Function for each single cell according to the objectives applicable in the context of that cell.

III. SOM SYSTEM DESIGN

The basic idea of the SOM approach is to separate the technical knowledge about how a SON Function affects the KPIs through a dedicated SCV Set, from the definition of the operator objectives. Afterwards, the SOM puts the separate SON Function and objective models together and determines the *best* combination of SCV Sets, i.e., one SCV Set per SON Function per network cell.

Figure 1 depicts a functional overview of the SOM system and the configuration process which consists of two steps. First, the *SON Function model combination* step merges the models of all available SON Functions into a *combined SON Function model*, which allows the estimation of the network performance for combinations of SCV Sets. This step needs to be performed whenever a SON Function model changes or a new model is added. Second, the *configuration selection* step determines the applicable objectives for the current cell context and evaluates the network performance estimations from the combined SON Function model against these objectives. Thereby, the SOM can select the best combined SCV Set for all SON Functions in the cell and deploys the changed SCVs to the network if they differ from the current configuration. Note that this step depends on the context of the cell and is performed iteratively for each and every cell. The configuration selection step is triggered by events which are raised by entities external to the SOM, e.g., a timer raising events in regular intervals, or a Configuration Management (CM) system informing the SOM about changes in the network layout.

The basic idea for combining the SON Function models and their joint evaluation is founded on a set-based description of the possible KPI values through some configuration, and

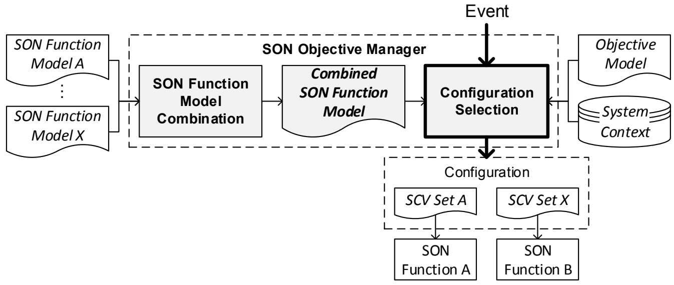

Figure 1. Functional overview of the SOM

the expectations of the operator regarding the KPI values. This allows two interpretations: a *pessimistic view* and an *optimistic view*. In the former, a KPI value is possible for a combined SCV Set if it is possible for a single SCV Set of the combination. In the latter, a KPI value is possible for a combined SCV Set if it is possible for each and every single SCV Set of the combination. In both cases, an objective is satisfied if the possible KPI values are a subset of those KPI values expected by the operator. Hence, the pessimistic view sees all SCV combinations which definitely meet the objectives as satisfying, whereas the optimistic view sees all SCV combinations which maybe meet the objectives as satisfying. This paper focuses on the optimistic view as it provides a higher potential for satisfying operator objectives, and thus, makes it more appealing for SON Management.

A. SON Function Model Combination

In principle, a SON Function model defines predicted effects on KPI values, by a specific SCV Set for a SON Function, without considering other SON Functions. Analogous, the combined SON Function model makes a forecast on the effect of a combination of SCV Sets, i.e., one for each SON Function.

1) SON Function Model: The model for a SON Function f defines a mapping FM^f between a set of possible SCV Sets S^f and their effect indicators on the KPIs E^f.

$$\mathrm{FM}^f : S^f \mapsto E^f \tag{4}$$

$$E^f = \left\{\varepsilon_1^f, \varepsilon_2^f, \ldots, \varepsilon_{|E^f|}^f\right\} \tag{5}$$

The SON Functions models are usually created by the manufacturer of the respective SON Function, but the SON Functions themselves are generally provided as black-boxes in order to reveal as little information as possible about their internal logic. The concrete value a KPI takes under some SON Function configuration can depend on the concrete mobile network, hence, the SON Function models need to provide as much information as necessary for operations but as little as possible. A SON Function optimises one or several dedicated KPIs, e.g., an MRO Function optimises HOSR, and the SON Function is usually configured such that it keeps the KPI value above or below some threshold, e.g., DCR $\leq 2\%$ and HOSR $\geq 99\%$. However, a SON Function might affect a KPI in less predictable ways, i.e., the manufacturer can solely predict that the KPI value is maximised or minimised, or a SON Function might have no effect at all on a certain KPI.

Table I. OVERVIEW OF THE COMBINED EFFECTS ON A KPI WITH THE DOMAIN $\mathrm{Dom} = [0, 100]$ FOR AN EXAMPLE WITH TWO SCV SETS.

p		$\uparrow$	$\downarrow$	$\leftrightarrow$	≥ 1	≥ 3	≤ 1	≤ 3
	φ	$[100]$	$[0]$	$[0, 100]$	$[1, 100]$	$[3, 100]$	$[0, 1]$	$[0, 3]$
$\uparrow$	$[100]$	$[100]$						
$\downarrow$	$[0]$	$\emptyset$	$[0]$					
$\leftrightarrow$	$[0, 100]$	$[100]$	$[0]$	$[0, 100]$				
≥ 1	$[1, 100]$	$[100]$	$\emptyset$	$[1, 100]$	$[1, 100]$			
≥ 3	$[3, 100]$	$[100]$	$\emptyset$	$[3, 100]$	$[3, 100]$	$[3, 100]$		
≤ 1	$[0, 1]$	$\emptyset$	$[0]$	$[0, 1]$	$\emptyset$	$\emptyset$	$[0, 1]$	
≤ 3	$[0, 3]$	$\emptyset$	$[0]$	$[0, 3]$	$[1, 3]$	$\emptyset$	$[0, 1]$	$[0, 3]$

Consequently, an effect indicator $\varepsilon^f \in E^f$ is represented by a set of tuples (k_i, p_i), with $k_i \in K$ indicating the affected KPI and p_i specifying the predicted value for k_i.

$$\varepsilon^f = \left\{ (k_1, p_1), (k_2, p_2), \ldots, \left(k_{|K_f|}, p_{|K_f|}\right) \right\} \tag{6}$$

The predicted value p_i can be defined as $\leq x$, $\geq x$, $\uparrow$, $\downarrow$, $\leftrightarrow$ with $x \in \mathrm{Dom}(k_i)$ indicating the effects of keeping k_i below or above some threshold x as well as the maximisation, minimisation, and non-influence of k_i. For instance, (DCR, ≤ 0.02) describes the effect that the DCR is kept below 2%. For simplicity, we assume that there is exactly one effect tuple for each KPI, i.e., $|\varepsilon^f| = |K|$.

The formalised effect $\varphi_s(k)$ of a KPI k for an SCV Set s of SON Function f is interpreted as a subset of the KPIs domain.

$$\varphi_s(k) = \begin{cases} [\max(\mathrm{Dom}(k))] & \text{if } (k, \uparrow) \in \mathrm{FM}^f(s) \\ [\min(\mathrm{Dom}(k))] & \text{if } (k, \downarrow) \in \mathrm{FM}^f(s) \\ [\mathrm{Dom}(k)] & \text{if } (k, \leftrightarrow) \in \mathrm{FM}^f(s) \\ [\min(\mathrm{Dom}(k)), x] & \text{if } (k, \leq x) \in \mathrm{FM}^f(s) \\ [x, \max(\mathrm{Dom}(k))] & \text{if } (k, \geq x) \in \mathrm{FM}^f(s) \end{cases} \tag{7}$$

$$\text{with } [x, y] = \{z | x \leq z \leq y\} \tag{8}$$

For instance, $(\mathrm{DCR}, \leq 0.02)$ is $\varphi_s(\mathrm{DCR}) = [0, 0.02]$.

2) Generation of the Combined SON Function Model: The main goal of the SON Function model combination is to predict the effects on the KPIs if several SON Functions with some SCV Set combination are concurrently active. Thereby, the set of possible SCV Set combinations is the cross product of the SCV Sets for all SON Functions.

$$\Sigma : S^{f_1} \times \cdots \times S^{f_{|F|}} \tag{9}$$

In the optimistic view, the combined effect $\tilde{\varphi}_\sigma(k)$ of an SCV Set combination $\sigma \in \Sigma$ on a KPI k is built by the intersection of the effects of the different SCV Sets, i.e.:

$$\tilde{\varphi}_\sigma(k) = \bigcap_{1 \leq i \leq |F|,\ s = \mathrm{proj}_i(\sigma)} \varphi_s(k) \tag{10}$$

with $\mathrm{proj}_i(\sigma)$ being the projection on the ith element of σ. Table I shows possible effect combinations for two SCV Sets.

As part of this combination process, conflicting configurations of SON Functions are identified. Conflicts are SCV Set combinations that might lead to an unstable and undesired system behaviour such as a constantly oscillating network reconfiguration. A pair of SCV Sets is in conflict if their possible effects on a KPI do not overlap, i.e., they do not agree on their optimisation target and optimise against each other In other words, the intersection of the formalized effects is empty, i.e., they have no common KPI value they both target.

$$\mathrm{isConf}(s_i, s_j) = \exists k \in K. \varphi_{s_i}(k) \cap \varphi_{s_j}(k) = \varnothing \tag{11}$$

Consequently, an SCV Set combination is conflicting if any two contained SCV Sets are in conflict. The set of conflicting SCV Set combinations Γ can thus be determined by:

$$\Gamma = \{\sigma \in \Sigma | \exists 1 \leq i < j \leq |F|. \mathrm{isConf}(\mathrm{proj}_i(\sigma), \mathrm{proj}_j(\sigma))\} \tag{12}$$

In Table I, conflicts are shaded grey.

The combined SON Function model, which is the result of the first step of the SOM process, consists of two sets: the set of all conflict-free SCV Set combinations Σ^Γ and the set of their combined effects Φ.

$$\Sigma^\Gamma = \Sigma \setminus \Gamma \tag{13}$$

$$\Phi = \left\{ \tilde{\varphi}_\sigma(\cdot) | \sigma \in \Sigma^\Gamma \right\} \tag{14}$$

Note that in the pessimistic view, the effects of the SCV Sets are combined by a union and a conflict is again determined if possible effects on a KPI do not overlap for two or more SCV Sets. Furthermore, in contrast to an optimistic view, neutral effects are interpreted as an empty range.

B. Configuration Selection

The configuration selection step scores the different SCV Set combinations and selects the best one for each and every cell. The score depends on the estimated system behaviour deduced from the combined SON Function model and the objective model.

1) Objective Model: The objective model defines the operator's objectives, i.e., for each KPI a target value together with a weight. The latter represents the importance of the objective and, thus, allows to trade-off the objectives against each other in case they cannot be satisfied simultaneously. Our approach is based on a weighted sum preference model which is very common due to its simplicity [4]. An objective can furthermore depend on operational context, e.g., it can vary for different times of the day, cell types and locations, or traffic patterns.

Formally, the target for a KPI is a set of acceptable values for the KPI, whereas the weight for a KPI is a real valued number between 0 and 1. Thereby, a higher weight represents a higher importance. Both, the KPI target t_k and the weight w_k, make up an objective $o_k \in O_k$ for a KPI $k \in K$.

$$o_k = (t_k, w_k) \ , \tag{15}$$

with $t_k \subseteq \mathrm{Dom}(k)$ and $w_k : [0, 1]$. For instance, the operator objective to keep the DCR below 2% with a medium weight is represented as $o_{\mathrm{DCR}} = ([0, 0.02], 0.5)$. The objective model can be seen as a function that maps a specific operational context $\chi \in X$ to a tuple of objectives for all $|K|$ KPIs, i.e.,

$$\mathrm{OM} : X \mapsto O_{k_1} \times \cdots \times O_{k_{|K|}} \tag{16}$$

A concrete syntax to express the objective model are production rules as presented in [3], for example:

```
IF location=rural THEN dcr ≤ 0.02 WITH 0.5
```

Thereby, the `IF` part is a logical formula which determines the applicability of the objective in a specific context, here, cells in a rural location. The `THEN` part defines the KPI target, here, the DCR must be below 2%. Finally, the `WITH` part defines the objective's weight, here, a medium weight. Notice that the semantics of the KPI target is similar with the interpretation of the KPI effects in (7).

2) Scoring of Combined SCV Sets: The configuration selection iterates over all cells of the network and selects the best combined SCV Set for each cell based on the combined SON Function model, the objective model, and the context: it calculates the utility for each applicable combined SCV Set, i.e., its degree of satisfaction of the context-dependent operator objectives, and selects the SCV Set combination with the highest utility. The following description outlines the selection process for a single network cell c with the context χ_c.

In order to calculate the utility for an SCV Set combination $\sigma \in \Sigma^\Gamma$, the configuration selection first determines the applicable objectives $\mathrm{OM}(\chi_c) = (o_{k_1}, \ldots, o_{k_{|K|}})$ for the cell context χ_c. Subsequently, it determines for each applicable objective $o_k = (t_k, w_k)$ whether σ satisfies the objective based on its possible values in the combined SON Function model $\tilde{\varphi}_\sigma \in \Phi$. As described in Section III, it must be ensured that all possible states of the cell configured with σ satisfy the objectives. Formally, this means that for a KPI $k \in K$, the satisfaction of the target t_k by a combined KPI value $\tilde{\varphi}_\sigma(k)$ is defined as

$$\mathrm{sat}(t_k, \tilde{\varphi}_\sigma(k)) = \begin{cases} 1 & \text{if } \tilde{\varphi}_\sigma(k) \subseteq t_k \\ 0 & \text{otherwise} \end{cases} \tag{17}$$

Since the objective model is based on the weighted sum preference model, the utility of a combined SCV Set σ is, in principle, the sum of the satisfaction values multiplied with the objective weight over all KPIs. However, it is advisable to use normalised objective weights such that a utility of 1 means the satisfaction of all objectives. As a result, the utility for a combined SCV Set σ is calculated as

$$U(\sigma) = \sum_{k \in K} \mathrm{sat}(t_k, \tilde{\varphi}_\sigma(k)) \frac{w_k}{\bar{w}} \tag{18}$$

with $\bar{w} = \sum_{i \in K} w_i$.

The combined SCV Set σ with the highest utility $U(\sigma)$ is the one which satisfies the operator objectives the most. Hence, it should be selected and configured for the network cell c. However, if $U(\sigma) < 1$ then this means that not all objectives could be satisfied by the configuration. This important feedback can be additionally provided to the operator. In case that two or more combined SCV Sets have the same utility, one of them is chosen randomly since they both fulfil the operator objectives to the same degree.

IV. Example

In this section, we exemplify our concept with the two SON Functions MRO and MLB, each with two SCV Sets, and three KPIs, namely DCR, HOSR, and Load. Note that the three KPIs all have the domain $[0, 1]$. Table II depicts

Table II. SON Function model combination for MRO and MLB

SON Function			MRO	
	Effect Indicator		$\varepsilon^{\mathrm{MRO}}_{s_1} = \{(\mathrm{DCR}, \downarrow), (\mathrm{HOSR}, \leftrightarrow), (\mathrm{Load}, \leq 0.65)\}$	$\varepsilon^{\mathrm{MRO}}_{s_2} = \{(\mathrm{DCR}, \leftrightarrow), (\mathrm{HOSR}, \geq 0.99), (\mathrm{Load}, \leftrightarrow)\}$
		Effect	$\varphi^{\mathrm{MRO}}_{s_1}(\mathrm{DCR}) = [0]$ $\varphi^{\mathrm{MRO}}_{s_1}(\mathrm{HOSR}) = [0, 1]$ $\varphi^{\mathrm{MRO}}_{s_1}(\mathrm{Load}) = [0, 0.65]$	$\varphi^{\mathrm{MRO}}_{s_2}(\mathrm{DCR}) = [0, 1]$ $\varphi^{\mathrm{MRO}}_{s_2}(\mathrm{HOSR}) = [0.99, 1]$ $\varphi^{\mathrm{MRO}}_{s_2}(\mathrm{Load}) = [0, 1]$
MLB	$\varepsilon^{\mathrm{MLB}}_{s_1} = \{(\mathrm{DCR}, \leftrightarrow), (\mathrm{HOSR}, \downarrow), (\mathrm{Load}, \leq 0.6)\}$	$\varphi^{\mathrm{MLB}}_{s_1}(\mathrm{DCR}) = [0, 1]$ $\varphi^{\mathrm{MLB}}_{s_1}(\mathrm{HOSR}) = [0]$ $\varphi^{\mathrm{MLB}}_{s_1}(\mathrm{Load}) = [0, 0.6]$	$\tilde{\varphi}_{\sigma_{11}}(\mathrm{DCR}) = [0]$ $\tilde{\varphi}_{\sigma_{11}}(\mathrm{HOSR}) = [0]$ $\tilde{\varphi}_{\sigma_{11}}(\mathrm{Load}) = [0, 0.6]$	$\tilde{\varphi}_{\sigma_{12}}(\mathrm{DCR}) = [0, 1]$ $\tilde{\varphi}_{\sigma_{12}}(\mathrm{HOSR}) = \emptyset$ $\tilde{\varphi}_{\sigma_{12}}(\mathrm{Load}) = [0, 0.6]$
	$\varepsilon^{\mathrm{MLB}}_{s_2} = \{(\mathrm{DCR}, \leq 0.02), (\mathrm{HOSR}, \leftrightarrow), (\mathrm{Load}, \leq 0.5)\}$	$\varphi^{\mathrm{MLB}}_{s_2}(\mathrm{DCR}) = [0, 0.02]$ $\varphi^{\mathrm{MLB}}_{s_2}(\mathrm{HOSR}) = [0, 1]$ $\varphi^{\mathrm{MLB}}_{s_2}(\mathrm{Load}) = [0, 0.5]$	$\tilde{\varphi}_{\sigma_{21}}(\mathrm{DCR}) = [0]$ $\tilde{\varphi}_{\sigma_{21}}(\mathrm{HOSR}) = [0, 1]$ $\tilde{\varphi}_{\sigma_{21}}(\mathrm{Load}) = [0, 0.5]$	$\tilde{\varphi}_{\sigma_{22}}(\mathrm{DCR}) = [0, 0.02]$ $\tilde{\varphi}_{\sigma_{22}}(\mathrm{HOSR}) = [0.99, 1]$ $\tilde{\varphi}_{\sigma_{22}}(\mathrm{Load}) = [0, 0.5]$

Table III. Scoring of the exemplary combined SCV Sets

	$o_{\mathrm{DCR}} = ([0, 0.02], 0.5)$			$o_{\mathrm{HOSR}} = ([0.95, 1], 0.2)$			$o_{\mathrm{Load}} = ([0, 0.5], 0.3)$			$U(\cdot)$
	$\tilde{\varphi}_\cdot(\mathrm{DCR})$	$\mathrm{sat}(\cdot)$	w_{DCR}	$\tilde{\varphi}_\cdot(\mathrm{HOSR})$	$\mathrm{sat}(\cdot)$	w_{HOSR}	$\tilde{\varphi}_\cdot(\mathrm{Load})$	$\mathrm{sat}(\cdot)$	w_{Load}	
σ_{11}	$[0]$	1		$[0]$	0		$[0, 0.6]$	0		0.5
σ_{21}	$[0]$	1	0.5	$[0, 1]$	0	0.2	$[0, 0.5]$	1	0.3	0.8
σ_{22}	$[0, 0.02]$	1		$[0.99, 1]$	1		$[0, 0.5]$	1		1.0

the SON Function models as well as the resulting combined SON Function model. On the one hand, the lines on the top and those on the left show the effect indicators as well as the KPI effects for the two SCV Sets of MRO and MLB respectively. On the other hand, the cells in the middle show the resulting combined effects $\tilde{\varphi}$ for the combination of the SCV Sets indicated by the row and column. As can be seen, s_1^{MLB} optimises HOSR in a way that its value will be minimised whereas s_2^{MRO} optimises against s_1^{MLB} since its usage would lead to a value ≥ 0.99 for HOSR. According to (11), this is denoted as a conflict since the intersection of $\varphi^{\mathrm{MLB}}_{s_1}(\mathrm{HOSR}) = [0]$ and $\varphi^{\mathrm{MRO}}_{s_2}(\mathrm{HOSR}) = [0.99, 1]$ results in an empty set. Hence, the set of conflict-free SCV Set combinations is $\Sigma^\Gamma = \{\sigma_{11}, \sigma_{21}, \sigma_{22}\}$.

Table III visualises the scoring of the conflict-free combined SCV Sets in the configuration selection step. Thereby, the columns in the header depict the objectives for the three KPIs and the rows show the performed computations for each combined SCV Set. As can be seen, combined SCV Set σ_{11} does only satisfy objective o_{DCR} and, thus, has an overall utility of 0.5. SCV Set combination σ_{21} does satisfy o_{DCR} and o_{Load} which leads to an overall utility of 0.8. Since the configuration σ_2 satisfies all objectives, it gets with 1.0 the highest score and, consequently, is selected.

V. Related Work

Most of the prior work on goal- or objective-driven management of autonomic systems assumes that the internal logic of the autonomic functions, i.e., the SON Functions, can be directly defined as a policy. This enables the operator to gain full knowledge of the SON Function algorithms, allows a prediction of their behaviour and effects, and facilitates their design such that they interfere as little as possible, i.e., such that no two SON Functions affect the same objective. However, this requires the manufacturers to provide a detailed action model and reveal the details of their SON Functions.

A two-step approach for goal refinement and network management policy creation is described in [5]. First, high-level goals, i.e., desired system states after event occurrences, are manually refined into low-level goals based on refinement patterns. Second, policy rules, i.e., sequences of actions in response to events, are derived using abduction based on a detailed semantic description of the actions in form of pre- and postconditions. In [6] and [7], the authors describe similar concepts where the action effects are predicted by forecast functions, which are assumed to either be given or be learned.

In the context of autonomic computing research, the Self-Net project [8] defines the policy as a set of rules describing the behaviour of the system at a low level, i.e., which NCPs should be changed in response to some problem. When lifting this approach to a higher abstraction level the rules describe the SCV Sets for SON Functions, but it is left to the operator to define a conflict-free policy satisfying the objectives. The GANA architecture [9] can be seen as a similar approach.

Several projects working on SON touch SON Management, but they mainly describe abstract ideas without providing detailed solutions regarding the problems discussed in this paper. SOCRATES [10] presents an idea describing the refinement of operator policies into SON Function specific policies such that the SON Functions are configured to achieve a common goal. UniverSelf [11] presents a governance component controlling Network Empowerment Mechanisms (NEMs) that refer to SON Functions. This component translates service level goals that are related to the objectives described in this paper to NEM level policies which compare to the SCV Sets. This translation is based on policy templates defined for the service level goals, i.e., they relate to the SON Function model. COMMUNE [12] describes a system model called GARSON containing a Policy Control Plane that controls the cognitive network functions, i.e., SON Functions, via "high-level goals". Therefore, the policy plane has a set of policy rules defining the configuration parameters of the algorithms in specific situations.

VI. Conclusion

This paper presents an extension of the SON Objective Manager (SOM) approach [3] for the dynamic configuration of a Self-Organising Network (SON)-enabled mobile network according to context-specific operator objectives. This is achieved by a SOM component which combines several specific SON Function models into a combined SON Function model, thereby identifying configuration conflicts, and evaluating this combination against a context-dependent objective model. In contrast to the former approach, the presented concept is put on a mathematical foundation for both the description of the promised system performance for a SON Function Configuration Parameter Value (SCV) Set in the SON Function model as well as the definition of the desired system performance by the operator. This enables more expressive SON Function models and objectives which allows the definition of thresholds for Key Performance Indicators (KPIs) in addition to minimisation or maximisation targets. Furthermore, it is possible to determine the best SCV Set over a set of weighted objectives instead of ranked objectives which allows to find better trade-offs between their satisfaction. The extended SOM concept is designed as a run-time system which does not create a policy at design-time but performs the computation at run-time, triggered by events.

A future step in this work on SON Management is to make the SON Function model context-dependent. This extension could account for the need to express that an SCV Set for a SON Function can produce diverse system behaviour in different operational contexts. However, it is an open question how the SON Function model can be created by the SON Function manufacturers in the first place. In order to solve this problem, the development of an automated method for model creation based on machine learning techniques is envisaged.

Acknowledgement

The research leading to these results has been carried out within the FP7 SEMAFOUR project [13] and has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 316384.

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