Adapting Policy-based Management of Future Networks using Collaborative Filtering Techniques

Roi Arapoglou, Iason-Dimitrios Rodis, Panagis Magdalinos, Nancy Alonistioti
Department of Informatics and Telecommunication
National and Kapodistrian University of Athens
Athens, Greece
{roiar, i.rodis, panagis, nancy}@di.uoa.gr

Abstract— **Future Networks constitute a complex and dynamic environment which network operators are called to orchestrate uniformly and efficiently. Among others, the increase in the number and heterogeneity of network infrastructure, the complexity of devices and protocols and the explosion in traffic demands are only "few" of the issues that network operators should take into consideration. Conventional network management schemes lack in automation, harmonization and efficiency, in order to handle such chaotic environments. Autonomic network management targets the governance of the behavior of autonomic and contemporary network entities, based on network operator requirements and business goals. Policies are considered as an effective tool for accomplishing a desirable high level control. In this paper, we present a novel policy-based network management framework, while enriching its ontology-oriented inference engine with collaborative filtering capabilities thus achieving the acceleration of the decision making process.**

Keywords—autonomics; network and service management; semantics; policies; collaborative filtering; personalization

I. Introduction

Thanks to Information and Communication Technologies (ICT) evolution and the competitiveness between service providers, end users are able to enjoy broadband connectivity and consume resource-hungry services at lower expenses. Future Networks [1] have evolved during the last decades constituting a field of glory for network operators, service providers, network infrastructure manufacturers and ICT researchers. The space between end users and incumbent network operators includes user needs for Quality of Service (QoS) provisioning, introduction of smart mobile devices, heterogeneous access technologies, complex core topologies, numerous content provider entities etc. Undoubtedly, taking care of all those different conditions becomes a riddle for network operators, who desperately seek for efficient network management tools. To make matters worse, those tools should be cost-effective, as management and operational costs comprise a substantial share of total cost ownership.

Research community has put forward the proposal of autonomics, as the most prevalent solution to the problem of Future Networks management. IBM's manifest for autonomic computing [2] is commonly recognized as the landmark for the introduction of autonomics in network management. Autonomic Network Elements (ANEs) are considered as a key part of Autonomic Network Management (ANM) systems. ANEs are computing entities capable of performing operations so as to achieve predefined high-level objectives, as those are defined by network operator. More specifically, ANEs are enriched with monitoring, decision and execution capabilities, usually referred as the MAPE-K model (Monitor-Analyze-Plan-Execute-Knowledge) [2]. Their purpose is to present a self-managed behavior and thus reduce human intervention (self-configuring, self-optimizing, self-healing, self-protecting). A plethora of research activities [3][4] and standardization bodies [5] are based on ANM in order to answer typical problems of Future Networks survival, including reduction in traffic delay, enhancements in load distribution, decrease in energy consumptions, identification of events of failure etc.

Concentrating on ANM system design, research efforts are grouped into two sectors, those that propose distributed network management models and those that follow more centralized solutions [6]. In distributed approaches, several autonomic managers exist, sparsely placed in the network. The ANM system is responsible for defining how these managers should communicate and co-operate so as to converge to a global optimum. In centralized approaches, one central entity is responsible for orchestrating low layer autonomic managers. ANM systems are usually realized through the use of policies; policies are the underlying factor that facilitate adaptability, intelligence and architectural formalism to these systems. Policies are semantic artifacts, expressed in the form of if-then-else rules representing operator goals and constrains. Modifying applied policies unveils one of their key features; their ability to reconfigure and adapt the behavior of the system without intervening in its operation. Those characteristics render policies as a promising tool for the construction of ANM systems that will address Future Network need for integration of always evolving technologies.

In this paper we present a policy-based network management framework, aiming at the orchestration of ANEs in a seamless and harmonized manner, as a result of enforcement of human (network operator) high level policy objectives. Automatic integration of newly deployed ANEs is permitted, through the use of XML and Web Ontology Language (OWL) [7]. The considered framework focuses on (a) specifying operator high level business goals, (b) serving ANE registration requests to the framework, (c) selecting the appropriate ANE(s) that best fit operator business goals and objectives. Particular emphasis is given on the inference engine of the proposed framework, as it realizes the decision making process. Inference engine uses both a well structured ontology and collaborative filtering (CF) techniques, so as to decongest ontology population. Moreover, we evaluate the introduction of collaborative based filtering, regarding its computational overhead and the acceleration of decision making process it achieves.

The remainder of this paper is organized as follows. Section II discusses related work, regarding enhancements in policy-based management systems. Section III provides a detailed view of the proposed policy-based network management framework. Section IV presents ontology population adaptation algorithm. Section V provides experimental results while Section VI concludes the paper and sketches future research directions.

II. Related Work

A plethora of research efforts concentrate on effective policy refinement schemes and possible solutions for the effective and dynamic adaptation of policy-based management schemes. In [8], a centralized policy-based network management (PBNM) framework is presented, extending IETF proposed PBNM standard [9] by addressing the need for dynamic changes in the network. Its novelty is the introduction of a multi-layer policy-based model; the considered layered approach distinguishes high-level management policies from their implementation. Transition between layers triggers semantic and syntactic procedures, which use mapping translators to interface between layers. The work focuses on heterogeneous mobile platforms attempting to achieve always best connect services. However, experimental analysis is limited to a simple handover use case, without any further evaluation of the framework.

A layered approach is also followed in [10], where a two-level policy-based framework is proposed, enriched with the dynamic reconfiguration of policy rules capabilities. Based on Reinforcement Learning techniques, already deployed policies are adapted dynamically while exploiting knowledge from the past. Experimental evaluation of the proposed framework is provided focusing mainly on learning performance. Adaptability of the network control mechanisms and on-the-fly derivation of new policy rules is not taken into consideration. Complexity analysis of the proposed framework is planned as a future work.

An attempt to evaluate the computational overhead of an ontology-based Network Management system is presented in [11]. In this work an ontology is constructed in order to model heterogeneous multi-tier networks and provision for the topology discovery process. An overview of the proposed framework is provided, accompanied by an extensive experimental analysis. Performance analysis concentrates on every distinct component of the framework by examining its delays, considering both the population of the system as well as the inference phase. The scalability of the framework is evaluated by increasing the cardinality of population sets. The outcome of this analysis is that inference process is directly affected by the number of instances in underlay ontology.

In [12] a policy-based SON coordination framework is presented. Its purpose is to manage a cellular mobile communication system, while guaranteeing configuration, optimization, performance, and fault management of multiple network elements deployed on a heterogeneous wireless environment. Policy-based management allows the administrator to adapt the behavior of complex SON functions in an optimal manner.

Work in [13] introduces a collaborative policy administration (CPA) framework in social network services. Even though the field of application is different to that of network management, the key novelty of CPA framework is the introduction of CF techniques in order to group similar policies and support not-well trained administrators. Compared to our contribution, CPA utilizes CF, in order to find matches between similar policies, while in our case CF is used so as to group ANEs with similar characteristics that conform to a certain policy and thus decongest ontology population. Moreover, the performance of CPA was examined and CF seems to outperform other category-based methods.

III. Policy Based Netwok Management Framework

The proposed policy-based network management framework is made up of four basic components, (i) Human to Network Interface, (ii) Policy Derivation and Management, (iii) Conflict Resolution, (iv) ANE Enforcement. Together, those four modules enable closed-loop, scalable, end-to-end QoS control and resource management in converged future networks. Fig. 1 provides a detailed view of the considered modules, as well as their interactions and information flow.

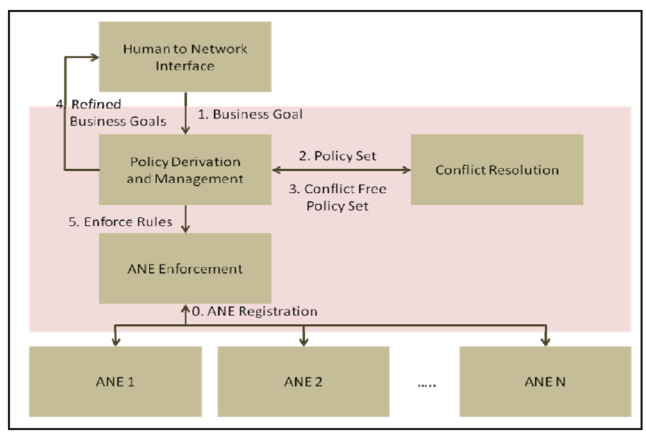

Fig. 1. Network Management Framework Architecture

A. *Human to Network Interface*

Human to Network Interface (HNI) is the intermediate between our considered framework and network operator. It provides user with a human friendly way for creating and editing policies, using high level business concepts. Such concepts may be related to the introduction of a new application, sets of user classes consuming network resources, Quality of Service (QoS) levels etc. High level policies, should be further translated into low level directives which in turn are enforced to ANEs, so as to control the behavior of one or several ANE instances. For this reason, the already defined business goals are forwarded to the Policy Derivation & Management block, in order to be transformed to network configuration (technology-specific terms) and leave the system to autonomously work out the situation and meet the objectives. The HNI also provides feedback to network operator by representing network indicators performance (e.g. load, jitter, etc) in a frequent manner.

B. Policy Derivation And Management

The Policy Derivation and Management (PDM) module is responsible for the effective translation of high level business objectives so as to (i) select the appropriate ANE conforming to those policies and (ii) generate low-level ANE-specific directives. Representation of high level concepts and rules is realized through the use of Ontologies (OWL) and ontological rules (SWRL). Ontologies constitute a mean to capture information and organize information and knowledge representation in a reusable and machine-readable format. Fig. 3 provides a graphical representation of our considered Ontology.

The translation process adopts the Policy Continuum model which was firstly introduced in [14]. Based on this approach, three levels are defined, namely Business, Service and ANE, each of which constitutes a different representation of the initial operator goal. The policies in Business level are modeled based on the ontology concepts reflecting considered objectives, close to natural language, while the policies of other levels are modeled based on SID information model [15]. Policies of different levels are linked in OWL by means of interoperability relationships between classes, which express the interrelation between subsequent levels, while SWRL rules are used for the transition between levels.

C. Conflict Resolution

Policy validation, policy conflict detection and resolution are the main tasks of the Conflict Resolution (CR) module. This process is based on identify-classify-detect-resolve conflict resolution cycle and performed in the final stage of policy translation (i.e. ANE level). CR detects conflicts between new policies and policies already stored in the framework. It also provides a conflict free policy set to PDM.

D. ANE Enforcement

The enforcement module constitutes a dual-direction communication endpoint between ANE instances and our policy-based network management framework. Due to the fact that ANE elements' design and development is realized by several network and service providers, there is a strong need for defining a formal information model in which manufacturers should conform to. Regarding the flow of information from ANE elements to the framework, a self-descriptive manifest of ANE instance is provided. This manifest, among others, includes information regarding the scope of ANE element, technology constraints, domain of network operation, provider characteristics etc. More details regarding the nature of the manifest, its role and structure can be found in [16]. On the other hand, in case of flow of information from the framework to ANE it includes low level directives to ANE in order to trigger its operation.

IV. Ontology Population Adaptation Algorithm

The enforcement module is responsible for examining the features a newly deployed ANE provides through its manifest and incorporate ANE into framework's ontology. A baseline approach dictates the instantiation of every class in the considered ontology (refer to Fig. 3) with values provided by ANE manifest. Although ontologies guarantee speed and reliability for building knowledge based systems, their computational overhead is proportional to the number of instances available. In our case, we consider a Future Network environment with abundance of service offer, thus numerous ANE registration requests are anticipated. To make matters worse, policy continuum and three-level translation poses extra overhead to the inference process, as registered ANEs are evaluated under different network operator rules and constraints.

Thus, following a naive baseline approach seems to be prohibitive for memory consumption and computational efficiency. The purpose of our work is to design a lightweight mechanism which populates the considered ontology in a conservative manner, regardless of the load of ANE registration requests. Influenced by the nature of recommendation systems, we encounter the use of CF techniques as a mean to filter large datasets and find common patterns. Due to the common features with our problem formulation, we introduce the use of CF in ontology population process, so as to address the aforementioned challenge. In Fig. 2 we present ontology population algorithm in a stepwise manner.

Input: ANE_i Registration Request, Recommendation Set (*RS*), Ontology Classes (*OntC*)
Output: instantiate ANE_i in *RS* and *OntC*
  Service ANE_i registration request
  For each representative ANE_j of *RS* **calculate**

$$similarity_{i,j} \leftarrow \frac{2\,|F_i \cap F_j|}{|F_i| + |F_j|}$$

  end for
  Set max($similarity_{ij}$) as s^{ij}
  If (s^{ij} > threshold)
    Insert ANE_i to ANE_j group
  else
    Instantiate ANE_i in *OntC*
    Insert ANE_i to RS
  end if

Fig. 2. Ontology Population and Adaptation pseudocode

Initially, we consider a set of ANEs which have been registered in the past and their manifests are stored in framework repository. Those ANEs are being held into groups, in accordance to how similar behavior they do present. The features used so as to evaluate the similarity between ANEs are the functionality family they belong to, the network technology they serve, the knowledge they produce and the

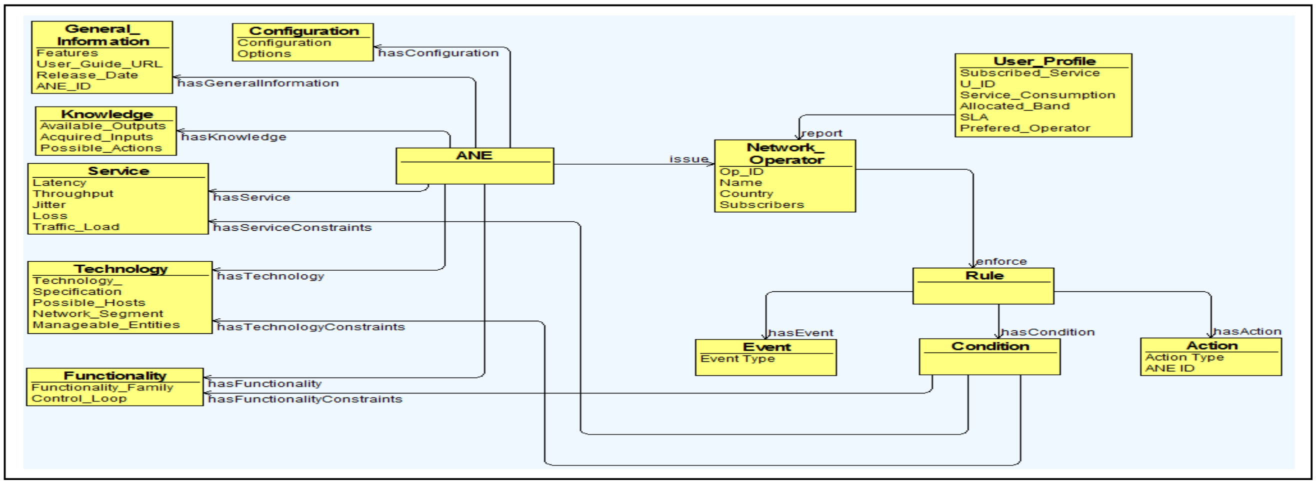

Fig. 3. Ontology

actions they enforce. Those features are also encountered in Fig. 3. For each group in the repository, a representative ANE is defined, for future calculations and field matching. Representative ANEs from all groups constitute a recommendation set (RS). During the registration of a new manifest and the extraction of the abovementioned fields take place. An iterative process then follows where the new ANE is compared to ANEs belonging to the RS. Similarity between couples of ANEs is calculated using Sørensen similarity index [17], where $F_i=\{f_{1i},f_{2i}...f_{Ni}\}$ is the set of features of ANE_i and $F_j=\{f_{1j},f_{2j}...f_{Nj}\}$ the features of representative ANE_j. In case ANE_i presents similar behavior with one of the ANEs in the RS, then considered ANE is inserted to the appropriate group and its manifest is stored in framework's repository. Otherwise, a new entry to the RS takes place, along with the instantiation of the ontology with features extracted from the ANE_i manifest. Threshold value is considered to be zero, as ANE features follow classic set theory (i.e. either be identical or not). A thesaurus of synonyms is also defined in our system, in order to resolve ambiguities. Table I provides an indicative thesaurus example.

TABLE I. SYNONYMS THESAURUS EXAMPLE

Feature	Synonyms		
Functionality Family	Energy Efficiency	Energy Consumption	Energy Saving
	Anomaly Detection	Failure Prediction	Fault Diagnosis
Network Technology	IEEE 802.11	WLAN	Wi-Fi
	LTE	4G LTE	E-UTRA
Possible Actions	Inter-Cell Interference Coordination	ICIC	Coverage and Capacity Optimization
	Load Balancing	Load Distribution	Load Decongestion

The complexity of the proposed ontology population and adaptation algorithm is proportional to the cardinality N of the RS (O(N)). Overhead imposed for the introduction of a new ANE into RS is O(1). Due to space limitations we omit further details related to the design and implementation of the considered algorithm and the framework as a whole. In order to shed light into the technical aspects of our work we provide the source code of the framework, accompanied with log-files and detailed explanation about the experiments at [18].

V. PERFORMANCE EVALUATION

In order to assess the performance of our framework and validate its feasibility, we have conducted a set of experiments. Our purpose is to measure the overhead imposed due to the introduction of CF techniques. In these experiments we measure (i) the delay for the incorporation of new ANE requests into the management framework, (ii) the delay for the translation process and the proper selection of ANEs that fulfill network operator goals. In the experiment we have varied the following parameters: (i) the number of concurrent ANEs' registration requests and (ii) the cardinality of the usage pattern repository.

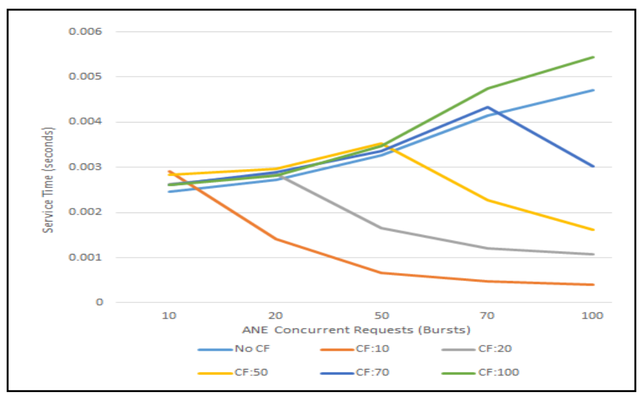

Fig. 4. ANE Registration Performance

Fig. 4 presents the time needed in order to serve registration requests from newly deployed ANEs. More specifically, we have examined the baseline approach where no CF technique is used and the case where CF is exploited, with different rates of similarity. Also we scale the number of burst requests of ANEs, so as to examine the performance of the system. Regarding the baseline approach, the required service time (manifest reading, instantiation to ontology) increases as the number of concurrent requests increases. Furthermore, the performance with CF depends on the overhead from requests as well as on the probability that several ANEs exhibit similar behavior. For instance, in case we have 50 distinct families (CF:50) with different functionalities, the baseline approach slightly outperforms CF:50 until 50 concurrent requests. However, in case of 70 or more burst requests CF:50 overhead decreases sharply.

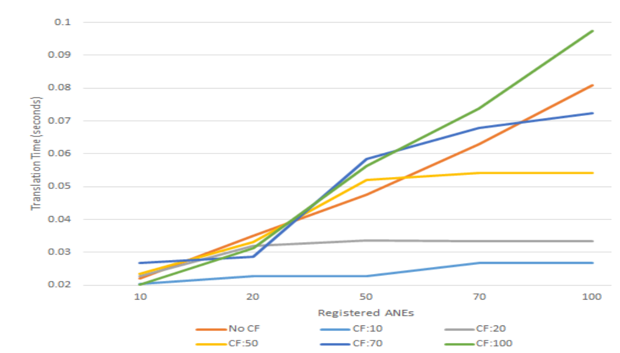

Fig. 5. Policy Translation Performance

Accordingly, Fig. 5 illustrates the performance of the framework, in order to translate policies, defined by the operator. CF outperforms the baseline approach (No CF), in cases where the size of RS is relatively small, compared to the number of ANEs registered to the framework. For instance, in case where 20 ANEs exist in the system, inference process overhead is about 0.035 seconds for the baseline approach, while translation process takes 0.022 seconds, when half of ANEs present similar functionality (CF:10). On the other hand, in case of 100 ANEs registered to the system baseline approach needs 0.08 seconds and CF:100 needs 0.097 seconds.

The outcome deduced from the experimental analysis for the use of CF techniques is that during the registration of new ANEs to the system; the computational overhead is larger, compared to the baseline case. The reason is that extra calculations take place in order to examine whether similarity exist with previously subscribed ANEs. Also, the instantiation to the ontology is possible in case of no similarity. On the other hand, the gain from the use of CF techniques is obvious at the translation phase, as ontology population is smaller and inference process takes place faster. We should also keep in mind that registration process is considered as an “off-line” process, as it does not affect decisions that framework produces for the network operator. The latter addresses the challenge for efficient orchestration of dense heterogeneous networks.

VI. Conclusion and Future Work

In this paper we have presented a novel policy-based network management framework. The innovation of this work is the introduction of collaborative filtering techniques into ontology instantiation process, so as to decrease ontology population and accelerate inference process. We have provided a detailed description of our framework and its considered ontology, along with the adaptation algorithm.The proposed framework has been evaluated under varying degree of registration requests and cardinality of usage pattern repository. In addition, a comparison has been made between the baseline approach and our proposed solution. Our future work will focus on the optimization of the architecture’s performance and the extension of policy-based network management framework so as to provide recommendations for ANEs that work in cooperation with the ANEs derived by the translation process , in case of real network conditions.

Acknowledgment

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement Univerself n° 257513.

References

[1] Stuckmann, P.; Zimmermann, R., "European research on future Internet design," IEEE Wireless Communications, vol.16, no.5, pp.14,22, October 2009

[2] Kephart, J.O.; Chess, D., “The vision of autonomic computing,” Computer, vol. 36, no. 1, pp. 41-50, January 2003.

[3] McCann, J.; Huebscher, M., "A survey of Autonomic Computing - degrees, models and applications," ACM Computing Surveys, 2007

[4] Samaan, N.; Karmouch, A., "Towards Autonomic Network Management: an Analysis of Current and Future Research Directions," IEEE Communications Surveys & Tutorials, vol.11, no.3, pp.22,36, 3rd Quarter 2009

[5] ETSI GS AFI 002: Autonomic network engineering for the self-managing Future Internet (AFI): GANA Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management. Publication expected by ETSI within Aug-Sep2011.

[6] Movahedi, Z.; Ayari, M.; Langar, R.; Pujolle, G., "A Survey of Autonomic Network Architectures and Evaluation Criteria," IEEE Communications Surveys & Tutorials, vol.14, no.2, pp.464,490, Second Quarter 2012

[7] http://www.w3.org/TR/owl-features/

[8] Keshariya, M.; Hunt, R., "A new architecture for performance-based policy management in heterogeneous wireless networks," in the Proceeding of Mobility '08, International Conference on Mobile Technology, Applications, and Systems, NY, USA, 2008

[9] http://datatracker.ietf.org/wg/policy/charter/

[10] Zhao, Z.; Chen, J.; Crepsi, N.,"A Policy-Based Framework for Autonomic Reconfiguration Management in Heterogeneous Networks," in the Proceedings of the 7th International Conference on Mobile and Ubiquitous Multimedia, MUM '08, NY, USA, 2008

[11] Frye, L.; Cheng, L., "A Network Management System for a Heterogeneous, Multi-Tier Network," Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE , pp.1,5, 6-10 Dec. 2010

[12] Bandh, T.; Romeikat, R.; Sanneck, H.; Haitao Tang, "Policy-based coordination and management of SON functions," Integrated Network Management (IM), 2011 IFIP/IEEE International Symposium on , vol., no., pp.827,840, 23-27 May 2011

[13] Han, W.; Fang, Z.; Yang, L.T.; Pan, G.; Wu, Z., "Collaborative Policy Administration," IEEE Transactions on Parallel and Distributed Systems, vol.25, no.2, pp.498,507, Feb. 2014

[14] Davy, S.; Jennings, B.; Strassner, J.,‘The Policy Continuum – A Formal Model,’ in Proc. of the 2nd IEEE International Workshop on Modelling Autonomic Communications Environments, MACE, 65–79, 2007.

[15] SID: http://www.tmforum.org/InformationFramework/1684/home.html

[16] Univerself Deliverable D2.4 “Unified Management Framework Specifications-Release 3", http://www.univerself-project.eu/

[17] TA. Sorensen, “A method of establishing groups of equal amplitude inplant sociology based on similarity of species content, and its application to analyses of the vegetation on Danish commons”, K dan Vidensk SelskBiol Skr 5, 1948, pp. 1-34.

[18] http://kandalf.di.uoa.gr/CAMAD_2014