Self-management in Future Internet Wireless Networks: Dynamic Resource Allocation and Traffic Routing for Multi-service Provisioning

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Abstract. Evolution towards the Future (Internet) networks necessitates inclusion of self-management capabilities in modern network infrastructures, for a satisfactory provision of related services and for preserving network performance. We have considered a specific targeted methodology, in the form of the *generic cognitive cycle model,* which includes three distinct processes (i.e. *Monitoring, Decision Making and Execution*), known as the "MDE" model, able to support dynamic resource allocation and traffic routing schemes. For further understanding of the issue we have examined two essential use-cases of practical interest, both in the context of modern wireless infrastructures: The former was about dynamic spectrum re-allocation for efficient use of traffic, while the latter has examined intelligent dynamic traffic management for handling network overloads, to avoid congestion.

Keywords: Autonomic communications, cognitive networks, Future Internet, generic cognitive cycle model, self-configuration, self-management, self-organization, spectrum re-allocation, traffic routing, WiMAX.

1 Introduction

The scope of the global Internet implicates much more than a "simple communication" system. The current Internet practically "unlocks" the global wealth of information and knowledge while the offered feature of "universality" allows formerly unconnected

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people and organisations with similar and diverse interests to find each other, thus resulting in new and wide-ranging communities of interest, supply chains, and markets (and networks) for several intents [1]. Today's Internet has become the indispensable means for networked innovation and a proper "highway" to globalisation and circulation of services/facilities and knowledge. Its size, complexity and role in modern society has far exceeded the original expectations of its creators. With the further deployment of wireless and mobile technologies, the number of users is expected to jump to some 4 billion in a few years.

In this fast evolutionary context, networks and services of the future continue to generate new economic opportunities with new classes of networked applications, whilst reducing corresponding operational expenditures [2]. The actual challenge faced by all relevant sectors (i.e. the state, public sector, private businesses, manufacturers, operators and service/application providers, users, etc.) is to "properly deliver" the next generation of ubiquitous and converged networks and services for communication, computing and media [3], as several societal and commercial usages are strongly "pushing" the current Internet architecture to its "limits". As the Internet expands its effectiveness, a multiplicity of novel and innovative services is introduced, demanding an environment able to support innovation, creativity and economic growth. Thus, the issue of the *"Future Internet (FI)"* is attracting more and more attention, as it impacts all underlying network technologies.

The Future Internet will provide the means to share and distribute new multimedia content and services, together with appropriate network resources and related facilities, with superior quality and striking flexibility, in a trusted and personalized way, improving quality of life and safety. Such an option also entails overcoming the scalability, flexibility, dependability and security bottlenecks, as today's network and service architectures are primarily "static" and able to support a limited number of devices, service features and limited confidence. Novel infrastructures will permit the emergence (or "re-shaping") of a large variety of business and economic models capable of dynamic and seamless end-to-end composition of resources across a multiplicity of devices, networks, providers and service domains.

2 Self-management Activities in the Future Internet

An increasing number of processes (many of which have explicit business impacts) need to be automated in the networks of the future, i.e. they have to be performed upon relevant autonomous decisions, without any human intervention. Today's ICT systems are not inherently able to "learn" from past (or current) experience and cannot contextualize and adapt to evolutionary processes, based on their own observation and learning processes. However, many ICT applications cannot be developed further, if there are no new breakthroughs in systems' intelligence and engineering [4]. Overcoming such technology "roadblocks" can permit the emergence of a wide range of opportunities in novel application fields, also including management (and re-configuration) of communications networks. In the context of the Future Internet, networks possessing cognitive features are often quoted as being one the "key" next-generation communications technologies [5] and are expected to lead to a much improved communication service, while providing efficient solutions to various problems currently experienced by market "actors". A prime challenge of the Future Internet is to provide means that will enable cognitive network management through dynamic, ad-hoc and optimized resource allocation and control, fault tolerance and robustness associated with real-time trouble shooting capabilities.

Thus, the attribute of autonomic network management (or "self-management") becomes an essential issue as it affects variable domains, most of which are essential for the effective network's behaviour, under several (predicted or even unpredicted) circumstances. The unified network infrastructure of the future (composing the "*Future Internet*") should support a number of parallel network architectures with distinctive traffic and quality characteristics. The anticipated traffic rates and new usage patterns challenge the current static and peak/best effort-based network configurations and/or dimensioning, calling for more efficient and flexible infrastructures that can support dynamic resource allocation and new traffic routing (i.e. "intelligent routing") schemes. Such options are further discussed in the continuity of the work, in the scope of two fundamental use-cases, dealing with network management.

2.1 Defining a Generic Cognitive Cycle for Self-management Purposes

In the context of the present work we propose a specific targeted methodology, intending to conceptualize and to develop novel concerns, for an effective realisation of the evolution towards to Future Internet networks/structures. The main aspect of the advancements of the current approach lies upon the introduction of cognition and autonomy in networks (also at the level of individual network elements-NEs) as well as in the collective ability of corresponding management functionalities. This presents the major driving concept based on the cognition in various system aspects and the realization of the Generic Cognitive Cycle Model (*Monitoring-Decision Making-Execution* or "*MDE*") as shown in Fig.1.

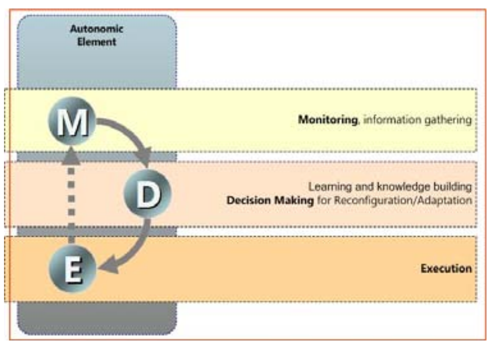

Fig. 1. Description of the Generic Cycle Cognitive Model

The above Generic Cognitive Cycle Model consists of three distinct phases, i.e. Monitoring (M), Decision-Making (D) and Execution (E). "*Monitoring*" involves gathering of information about the environment, and the internal state of any entity considered as an "*autonomic element*"[1]. "*Decision-Making*" includes learning, knowledge building and decision-making for reconfiguration and/or adaptation, by utilizing the developed knowledge model and situation awareness. Finally, the "*Execution*" process involves (self-) reconfiguration, software-component replacement or re-organization and optimisation actions. The model is present in several network elements (as well as in the collective management facilities) and constitutes advancements of current systems. It can ease the "transition" to the Future Internet by addressing multitudes of challenges (e.g. explicit protocol design for a wireless world, integrated functional design, alternative stacks, data-aware network equipment and handling service and network complexity) [6].

3 Autonomic Management of Future Internet

Defining and validating appropriate self-management methods (especially for a variety of network-related management issues) can facilitate, *significantly*, any process for making real Future Internet's vision. However, challenges emerge in terms of scalability, mobility, flexibility, security, trust and robustness of networks. In particular, *at the network level*, a major instigation lies on the proper "incorporation" of flexible and ad-hoc management capabilities.

Traditional network management involves complex labor-intensive processes performed by experts (humans and dedicated tools/systems). For example, some important configuration tasks such as installing or reconfiguring a system, provisioning network services and allocating resources typically engage a large number of activities involving multiple NEs. The latter may be associated with proprietary configuration management instrumentation and may also be spread across heterogeneous network domains thereby increasing the complexity of the relevant management activities. Human-guided (or "manual") processes currently involved with network management are rapidly reaching their "limits", as networks become more complex and implement a plethora of modern and innovative services. On the other hand, Future Internet networks will require minimal human involvement in the network planning and optimisation tasks; consequently, self-management can provide the proper countermeasures to that purpose [7]. Thus, related technologies are expected to pervade the next generation of network management systems and so to affect considerations for their deployment and exploitation, while the essential aim is to ensure that network continues to function, even if one or more nodes (or other elements) fail.

The rapid growth of Internet, both in terms of data traffic and in terms of diversity of services, has led to a high complexity of network architectures, which are even harder to manage. Challenges resulting from the current complex Internet architectures are manifold, and the goals for the envisioned architectures are sometimes conflicting. Future networks are complex systems with a large number of control mechanisms and

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[1] An "*autonomic element*" may be a network element (e.g., router, base station (BS), and mobile device), a network manager, or any software element that lies at the service layer. Such an element, equipped with embedded cognition, has a process for monitoring and perceiving internal and environmental conditions, and then for planning, deciding and adapting (self-reconfiguring) on relevant conditions.

parameters, acting at diverse time scales (*i.e. from milliseconds to hours, or even more*); noteworthy interdependencies can occur among them, usually accompanied by constraints on measurements, signalling and processing. Understanding, interpreting, analyzing, categorizing and handling such potential intricacies, can affect the design and the usage of effective network management functionalities. For example, recent actions demonstrate that newly added base stations are self-configured in a "*plug-and-play*" fashion, while existing base stations continuously self-optimize their operational algorithms and parameters in response to changes in network, traffic and environmental conditions. Adaptations and interventions are so desirable, in order to provide the targeted service availability and quality, as efficiently as possible. In the same approach, it should be expected that several flexible and cognitive network management and operation frameworks should be developed, to enable dynamic, ad-hoc and optimised resource allocation and control, administration with accounting that ensures expansion of usage, differentiated performance that can be accurately monitored, fault-tolerance and robustness, associated with real-time trouble shooting capabilities. It is essential for the novel management architectures to target self-organised operations and support cooperative network composition as well as service support across multiple operator and business domains. There is a variety of external and influencing available definition on self-management related work. In addition, many of the aspects of self-management are not defined as guiding definitions with practical realisation but as "light" visions that provide conceptualization of the features in a system.

In the following sections, we examine two distinct examples of how a self-management conformant to the *M-D-E* scheme (i.e., including *Monitoring* actions, *Decision-Making* complexities and *Execution* options) can be implemented in specific wireless network environments. Both cases depict examples of "practical" importance, as they are usually concerned by network operators. The first case relates to the performance management of a wireless network, where spectrum reallocation should take place, either when traffic requirements at a certain link exceed the maximum achievable limit or in order to avoid interference effects. The second use-case refers to the intelligent dynamic traffic management of a wireless network environment (also considering multi-service provisioning); the aim there is to suitably "handle" any potential network overloads and to avoid (or overcome) congestion phenomena that may affect network performance. The proposed analysis is based on high autonomy of NEs in order to allow distributed management, fast decisions, and continuous local optimization. The collection of issues presented indicates the complexity of the framework associated with cognitive processes in systems. The process is useful to formulate relevant criteria for defining "degrees of success", when handling situations of interest. The suggested use-cases can help to "add" novel operational capabilities on the underlying system, mainly by introducing distinctive self-management features. Benefits can be considered either in reducing (time-based or actions), removing or instructing human interventions for tackling situations in the relevant system. In fact, self-management methods deal with operational aspects of the system for which the reduction (or even the "removal") of human intervention is not the dominant criteria of success but for which there is a "collection" of evaluation criteria such as various delays, diverse consideration for throughputs, reduction or minimization of packet losses, thus affecting performance.

3.1 Dynamic Spectrum Reallocation for Traffic Handling

New wireless access technologies will continue to emerge, including new versions of 802.11 (WiFi), 802.16 (WiMAX), 3G cellular, ad-hoc mesh networks, and more. All these offer enhanced opportunities to the end-users: they provide more efficient coverage, make available higher data rates at greater distances, and improve the quality and capacity of communications, while offering customers greater choice and flexibility. However, current networking technology cannot always respond, *efficiently*, to complex problems which arise from increasingly bandwidth-demanding applications/services competing for scarce resources. When this correlates to complex network structures with variable parameters and network performance objectives, the task of selecting the ideal network "*operating state*" may seem difficult. In order to upgrade network's performance, self-management may be considered. This usually incorporates a number of distinct operations with pre-defined roles in the overall system. Currently, the immense majority of the wireless systems are using fixed spectrum blocks between different wireless links. While the vast majority of the frequency spectrum is licensed to different organizations, recent observations provide evidence that usage of the licensed spectrum is by far not complete neither in the time domain nor the spatial domain [8].The most important issue which concerns operators worldwide is the fact that these spectrum blocks are "pre-arranged" or "pre-assigned" and do not have the option of dynamic change, when traffic requirements at a certain link exceed the maximum achievable limit [9]. The same happens when there is interference at a link between a user and a Base Station (BS) or between two BSs – either man-made interference or interference caused due to natural phenomena (e.g. storms, rains, snow, etc.). In order to assure the proper functioning of the system as for both the above distinct cases, spectrum should be dynamically reallocated among the existing links either by "removing" a part of it from one link and then by reassigning it to another link, or by reallocating the whole spectrum that is normally used, conformant to the actual technical/regulatory requirements. Furthermore, modern applications (such as VoD (video-on-demand), HDTV (high definition TV), IPTV, etc.) require additional spectrum and, *therefore*, a dynamic spectrum management is appropriate. The need of introducing/deploying new wireless applications, necessitate the use of dynamic spectrum access to turn existing networks into dynamic spectrum access ones.

The following use-case relates to the occurrence of significant spectrum interference between cognitive radio links supporting wireless communications. In such cases, either a network (or a wireless node) "modifies" its transmission/reception parameters in order to efficiently communicate by avoiding interference, when the latter occurs. This parameters' alteration is based on the active monitoring of several factors in the external and internal radio environment such as RF spectrum, user behavior and actual network state. Such radios, able to have an adequate knowledge of their surrounding electromagnetic spectrum environment, can facilitate the entire system to make any proper adjustments/modifications to the transmission characteristics when necessary, to diminish interference [10] to the minimum possible extent and so to preserve its normal functioning [11]. The purpose is to achieve a dynamically coordinated spectrum sharing & to facilitate interoperability between systems ([12,13]) thus optimizing network capacity, coverage and QoS and achieving reductions on operational or capital expenses of the system [14]. Thus, detecting any unused spectrum and sharing it without harmful interference with users when there is a need, becomes an important network requirement [15,16]. Future wireless communications can have major benefits from such functionalities operated by reconfigurable networks and related terminals [17]. In the present case, the interconnected NEs can form dynamically collaborative structures in order to identify/solve specific configuration or optimization problems (e.g., optimal spectrum usage) to improve their behaviour locally, taking into account the global behaviour of the network compartment where they participate [18]. Each network element (or user equipment) can cooperate and exchange local information in a peer-to-peer mode in order to achieve global properties/behaviour. This means that if, for example, frequency 2 for the link between two BSs is running large applications (and so requires extension of its spectrum usage), then a block of spectrum from frequency 3 will be removed and reassigned to frequency 2, to fulfill extra requirements (Fig.2).

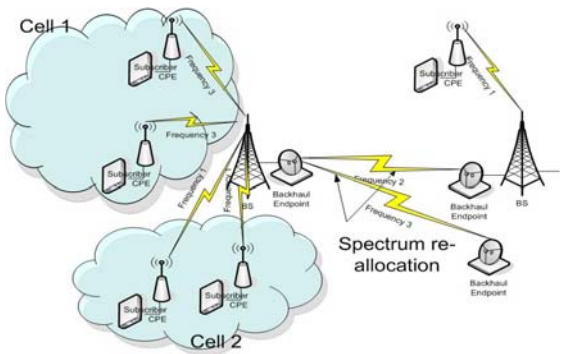

Fig. 2. Dynamic Spectrum Reallocation for efficient Traffic Use

The above example essentially relates to the network elements level (i.e. access points and BSs), where information has to be identified, collected, stored and treated, and then subsequent decisions have to be made. The case affects traffic transmission management, the decision for spectrum selection and for allocation capabilities of individual network elements (as well as "clusters" of them). We consider an approach conformant to *M-D-E* model.

Monitoring (M) data may include a variety of QoS and/or general wireless service performance indicators (i.e. data traffic, required link/service bandwidth, interference, signal coverage, (dynamic) network topology, available spectrum, utilization of spectrum, etc.). Data is to be collected and measurements are to be performed on a "conformant" basis, via suitable network counters. Measurements of channel characteristics and/or traffic aspects may then be processed to provide information for the related broader self-management activities: Here, the case essentially addresses the requirements of "*self-optimization*" and "*self-configuration*". The required accuracy (and periodicity) of collected information depends on specific mechanisms used. Each network elements (or mobile device), through the monitoring mechanisms collaborate with neighboring NEs, to exchange local monitoring data and detect inefficiencies or optimization opportunities. In more dynamic environments, such mechanisms are necessary to discover the neighboring network elements.

The *Decision Making (D)* process should refer to the identification of the "critical" physical parameters of operated wireless links (e.g. interference and network coverage) concurrently with the required bandwidth for supported services and the autonomic dynamic spectrum re-allocation between links to optimize network performance. The aim is to adapt, *appropriately*, the corresponding resource management parameters to sudden or to gradual variations in system traffic and/or propagation conditions. Performance measurements that derive either from individual NEs or are collectively calculated may prompt links to initiate autonomously a re-organization query in their vicinity, and decide a re-configuration action (i.e., spectrum re-allocation). The identification of the re-organization opportunities is the first step of the "negotiation phase"; it involves identification of available NEs and of spectrum resources, correspondingly. The negotiation among NEs includes policies and other local information exchange, to define the collaboration agreement among the involved entities and their interaction principles. After conclusion of that phase where available spectrum resources have been identified, then the involved elements "decide", in a distributed way, the new formation (i.e. spectrum re-allocation actions).

The *Execution (E)* phase mainly includes the processes of dynamically/ autonomously re-allocating spectrum between network links, to optimize traffic transmission and/or diminish harmful interference. Furthermore, policy rules and knowledge models are updated in the new formation, by considering the occurred reconfiguration action. Further evaluation can focus on determining whether wireless service provisioning can be improved (or preserved at a prescribed quality level considered as "adequate") by using cognitive dynamic spectrum re-allocation procedures for a flexible spectrum management and/or by examining spectrum utilization, QoS and network capacity criteria. In the same frame it is appropriate to evaluate the time required, success rate and gain of "self-management" actions, especially by comparing the effectiveness of the new formation to the previous one(s), and so "re-initiate" the *M-D-E* cycle.

3.2 Traffic Management for Multi-service Provisioning

The main issues traffic management [19] has to deal with are controlling and allocating network bandwidth, reducing delay, and minimizing congestion on networks [20]. The efficient management of network resources is very important for user requirements, especially in terms of bandwidth and service levels, for both operators and end-users. Almost all networks are subject to failure, in the sense that occasionally, for certain reasons, nodes can fail and so become unavailable to carry existing flow, thus leading to enormous service disruptions. A primary aim of network administration is the proper monitoring of routers/switches for "anomalous" traffic behaviour like outages, configuration changes, flash crowds and abuse. Identifying anomalous behavior is often based on ad-hoc methods developed from years of experience in managing networks [21]. Congestion can typically occur where multiple links feed into a single one. During periods of heavy congestion, directives can be dispatched to appropriate network modules to step-down traffic load to the network. As network congestion subsides, such directives can be dispatched to step-up traffic load until a normal level of traffic is restored [22]. Rate controls derived from traffic classification/prioritization can facilitate a meaningful congestion management [23], including prevention, avoidance, and finally recovery [24, 25].

Up-to-now, service providers desired to maintain their network(s) performance at satisfactory levels and so to keep an advanced QoS. The fast rising and gradual penetration of streaming services in the marketplace necessitates more enhanced reliability. By definition, a cognitive network is required to provide, over an extended period of time, better end-to-end performance than a non-cognitive one [26]. Cognition methods like "*self- configuration*" and "*self-organization*" can be used for improvement of the network performance via the proper handling of network traffic.

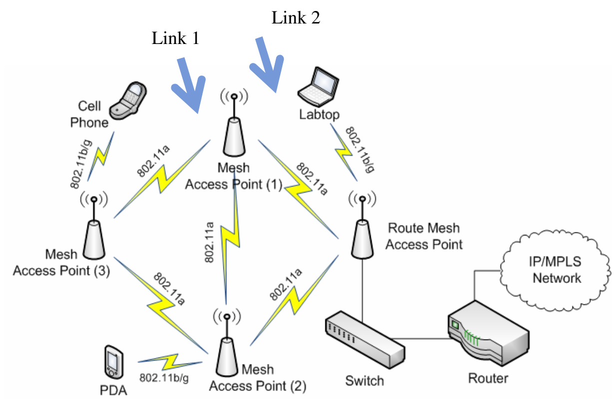

Fig. 3. Traffic Handling for Multi-Service Provisioning

The present use-case considers the improvement of congestion management in a large wireless network, supporting multiple services through dynamic traffic routing and source throttling. Congestion management is a very frequent and serious issue that network operators have to encounter; it directly impacts the overall network performance and, *correspondingly*, the customers' experience and satisfaction. The case concerns the situation when there is a bandwidth bottleneck at a certain wireless route directly affecting network performance, or when a certain link between two network nodes (e.g. routers) becomes suddenly congested. When this happens, then the load traffic should be routed to another appropriate link that can handle the extra traffic; otherwise, traffic may be distributed between a number of different links; or a notification can be sent to the relevant causal sources so that the latter to "*throttle*" their actual flows. The approach can use intelligent cognitive routers suitably programmed to acquire the traffic data of each link and, *when a congested link is detected*, to autonomously "re-route" traffic appropriately or to "signal"/notify the causal sources (as mentioned above). The case will take into account relevant traffic types and necessary resources. For example, Fig.3 illustrates the instance where the capacity of Link 1 is overloaded, for congestion reasons, and so extra traffic is routed to Link 2, to maintain overall network performance.

Monitoring (M) concerns measurement of current (and of average) loads to produce a variety of traffic (and occasionally of congestion) indicators, also in respect of QoS and service performance. Suitable parameters can be taken into account, which may include, *inter-alia*, identifying the controlled variable, the control structure, convergence and stability, and parameter configuration. Data should be collected appropriately, so that periodic measurements may be able to provide a dynamic "image" of the network loads, at proper time intervals. Once again, the required accuracy (and periodicity) of the collected information may depend on the specific mechanisms used. This use-case addresses the Future Internet requirements of "*self-optimization*" and "*self-configuration*". In several instances it could also deal with "*self-healing*", when network's performance is seriously threatened and immediate remedy is required, to avoid any potential corruption (or undesired "alteration") of network operation. The corresponding triggering event concerns the local recognized overload of a link for intermediate action and is initiated by performance data indicating high congestion between certain links in the network and/or associated performance degradation (in respect to resource allocation). Network overloads can seriously degrade the quality or availability of telecommunications services if they are not effectively controlled. Autonomic mechanisms will be triggered by procedures monitoring both network traffic and the performance of wireless service provisioning.

The Decision Making (D) process will react, autonomously, in an intermediate and longer term sense. Intermediate reactions will only have a few possibilities where in longer terms a general route re-configuration can take place. Requirements for appropriate overload controls and network traffic management can be considered, in terms of the conditions under which network links must operate and the behavior they should exhibit.

Execution (E) may implicate some among the following actions, that is: reconfiguration of routing tables, signaling of overload through causal sources, fair packet dropping and bandwidth reallocation. It should be expected that the appearance of network congestion phenomena should be reduced, while the overall network performance should be improved (or at least "preserved" at normal conditions).

In traditional networks, an overload situation over the shortest path results in significant packet loss. Self-management capabilities results in re-routing of packets along a path that has suitable resources available. This may occur either at network element level (where a proactive distribution of alternative routes allows local decision based on current load) or at network level (where overload indications can be the triggering event). Alternatively, suitable dynamic communication protocol mechanisms may use overload indications to reduce the amount of incoming traffic. In the previously examined use-case the system becomes able to "assess" its functional situation and to provide various operations targets that indicate a "desired operational status" (in this case for "solving" congestions).

4 Conclusion

Future Internet's vision affects an immense multiplicity of issues, and implicates major challenges for various domains of activities as it rapidly expands its effectiveness and penetrates several related environments (mainly network and service technologies). The perspective of autonomic network management (or "self-management") becomes a matter of "extreme priority" and of "prime importance" for the wider electronic communications sector, as it strongly influences network's behaviour. We have proposed a specific targeted methodology based on the introduction and the deployment of both cognition and autonomy in networks (also applicable at individual NEs). This methodology appears in the form of t*he generic cognitive cycle model (M-D-E)* able to facilitate a satisfactory transition to the Future Internet, when coupled with available technological advancements at the network level. In order to further analyze that concept, we have proposed and presented two essential use-cases for study, which both deal with practical network management situations: The first one relates to dynamic spectrum re-allocation for the purposes of the efficient use of traffic in a modern wireless network. The second refers to the intelligent dynamic traffic management of a wireless network environment (also considering multi-service provisioning) with the aim of suitably handling any potential network overloads and in order to avoid (or to overcome) congestion phenomena that may affect network performance. The network can optimize, repair, configure and protect itself on its own, without external intervention.

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