A Vision of Self-Evolving Network Management for Future Intelligent Vertical HetNet

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Abstract—Future integrated terrestrial-aerial-satellite networks will have to exhibit some unprecedented characteristics for the provision of both communications and computation services, and security for a tremendous number of devices with very broad and demanding requirements in an almost-ubiquitous manner. Although 3GPP introduced the concept of self-organization networks (SONs) in 4G and 5G documents to automate network management, even this progressive concept will face several challenges as it may not be sufficiently agile in coping with the immense levels of complexity, heterogeneity, and mobility in the envisioned beyond-5G integrated networks. In the presented vision, we discuss how future integrated networks can be intelligently and autonomously managed to efficiently utilize resources, reduce operational costs, and achieve the targeted Quality of Experience (QoE). We introduce the novel concept of “self-evolving networks (SENS)” framework, which utilizes artificial intelligence, enabled by machine learning (ML) algorithms, to make future integrated networks fully intelligent and automated with respect to the provision, adaptation, optimization, and management aspects of networking, communications, and computation. To envisage the concept of SEN in future integrated networks, we use the Intelligent Vertical Heterogeneous Network (I-VHetNet) architecture as our reference. The paper discusses five prominent communications and computation scenarios where SEN plays the main role in providing automated network management. Numerical results provide an insight on how the SEN framework improves the performance of future integrated networks. The paper presents the leading enablers and examines the challenges associated with the application of SEN concept in future integrated networks.

I. INTRODUCTION

To address the ever-increasing user demands of extremely high data rates with extremely low latency in an almost-ubiquitous manner, it has become essential to envision new ways of integrating terrestrial, aerial, and satellite networks. In the coming years, networks will undergo an unprecedented transformation that will make them substantially different from previous generations. This will require a radical paradigm shift in the way networks and services are managed and controlled. There is an emerging need to handle the increase in the overall complexity resulting from the transformation of networks into programmable, software-driven, service-based and holistically managed architectures, and the unprecedented agility and mobility, where users and base stations (BSs) will be mobile in three dimensions [1], [2].

Conventional model-based networks’ control and management solutions will not be suitable for these networks. Mathematical models are not dynamic and can not adapt to the variable environments of future networks. There is no single model that can cover all possible scenarios.

In this paper, we provide a vision on how future networks can be managed in order to efficiently utilise resources, reduce operational cost, and achieve the coveted QoE. We propose the self-evolving networks (SENSs) framework that utilizes data-driven intelligent real-time control to automate network management. For 4G and 5G, 3GPP proposed the concept of self-organizing network (SON) (Rel. 8-14) and machine learning (ML) empowered SON (Rel. 15-16), which focused on the autonomous configuration, optimization, and healing of an existing network that has a predefined set of radio resources. However, future networks will require a paradigm shift from classical SON, whereby the network adapts its functions to specific environment states, into a self-evolving network that can maintain its performance, under highly dynamic and complex environments. SEN will drive the network management from self-organization to continuous and automatic evolvement and be able to automatically react to unknown environments and triggers, requiring self-adaptive and resilient learning mechanisms. Unlike SON, SEN will be able to self-manage a network of networks that spans across multiple operators and ecosystems (e.g., satellite, aerial, and terrestrial networks). In addition, SEN will resolve conflicts and manage the coordination among the several entities in the future integrated networks. Moreover, SEN will consider the provision, optimization, and management of both communication and computational resources. Table I provides a comparison between SON and SEN concepts.

Artificial intelligence, enabled by ML algorithms, will work as the core of SEN engine and will be powered by both the communications environment’s collected data (e.g., spatial and temporal traffic distributions, user preferences, and mobility patterns) and external sources improvements such as novel technologies, emerging network components, and advanced communication services. We expect that ML will be effective in learning from experience and detecting changes. Thus, with such knowledge and self-awareness, continuous, intelligent, and automated decision-making can be made to evolve the network. For example, intelligent decisions can be made to inject more communications/computation resources/components, add services, or exploit technology advances in the network when there are expected demands for extra high data rates, ultra low latency edge computing, or new emerging applications. Fundamentally, SEN will support communication networks through intelligent and automated management, and communication networks will support the self-awareness, and the distributed and collaborative computing in SEN.

We utilize the intelligent vertical heterogeneous network (I-
TABLE I: A comparison of SON and SEN characteristics

| Characteristic                  | SON                                      | SEN                                      |
|--------------------------------|------------------------------------------|------------------------------------------|
| Scope                          | Operates in designated network or operator. | Across networks, operators, and ecosystems. |
| Dimensions                     | Communication and control.               | Communication, computing, control, caching, security & privacy. |
| AI/ML implementation           | Centralized or partially distributed (within a network or ecosystem). | Fully distributed across networks, operators, and ecosystems. |
| Intelligence deployment        | Lacks coordination and conflict avoidance among autonomic management functions of a SON | Ensures conflict-free and coordinated inter-working of multiple autonomic functions and multiple SONs that operate simultaneously in the same or interacting networks, operators, and ecosystems. |
| Coordination and conflict management | Security & privacy can be managed within a network or operator domain. | Security & privacy will be managed across networks, operators, and ecosystems. |
| Level of security & privacy   | Intelligence is applied in centralised or semi-centralised manner. | AI/ML application can be distributed across networks, operators, and ecosystems, where edge computing and UEs resources are used as well. |
| Distributed AI/ML              |                                          |                                          |

VHetNet) architecture, which is an extension of the work in [1], as a reference architecture to reflect the concept of SEN on future integrated networks. The I-VHetNet architecture jointly performs communications and computation tasks by fully utilizing satellite, aerial, and terrestrial networks. Figure 3 shows the SEN framework with I-VHetNet.

The contributions of this paper are as follows:

- We provide a vision of the SEN management framework, which is necessary to automate the management of services and network operation of future integrated networks.
- Based on the concept of SEN framework and the I-VHetNet architecture, we introduce five scenarios where SEN plays a vital role in providing automated network management.
- We present simulation results for a simple yet non-trivial system to compare the performance of SON and SEN for data offloading and computing in future networks.
- The main enablers and challenges associated with the application of SEN in future networks are highlighted.

In the next section, we introduce the concept of SENs and discuss how it differs from SONs. Section III presents an overview of I-VHetNet. In Section IV SENs enablers are discussed, and Section V presents the envisioned five scenarios, where SEN framework plays a vital role in providing automated network management along with numerical results. Several critical issues and challenges are discussed in Section VI and our conclusions are presented in Section VII.

II. SELF-EVOLVING NETWORKS

Future integrated networks will provide immense heterogeneous communication and computation resources. However, it will be almost impossible to achieve the coveted key performance indicators (KPIs) without intelligent and fully automated management of network services and operation. The adoption of manual or semi-manual network operation and management approaches in the evolved future communication networks will result in failing to achieve the required KPIs even though extensive communication and computation resources are available.

Recently, some ideas have emerged that call for the utilization of AI/ML in managing services and network operation. The knowledge defined network concept introduced in [4] utilizes Software-Defined Networking (SDN) and Network Analytics to facilitate the adoption of AI techniques in the context of network operation and control. The ETSI ZenGx network and Service Management (ZSM) group is formed with the goal to accelerate the definition of the required architecture and solutions in order to achieve full end-to-end automation of network and service management in the context of 5G. 3GPP has discussed the SON concept in Release 8 (LTE) and in all subsequent releases. SON refers to the automation of communications networks and the minimization of human intervention in the network management process [4]. SON provides the capabilities of self-configuration at the network deployment phase, self-optimization of network parameters, and self-healing to prevent/detect/correct network failures. SON presents significant limitations relative to the challenges facing future networks. The challenges are summarized in Figure 4, Table II provides a comparison between the characteristics of SON and SEN.

To fulfill the requirements of future integrated networks, network management should go beyond the concept of executing the pre-defined network management functions and should be able to automatically react to unknown environments and triggers. In SEN, network operation and service management automation will evolve through time. The network will not only learn the new environment but it will also be able to learn how to learn and what to learn.

The concept of SENs implements multi-level intelligent network management policies, which can perform across different domains, networks, operators, and even ecosystems (e.g., cellular or satellites ecosystems). SEN concept is supported by advances in ML (e.g., federated learning, online learning, continual learning), the availability of edge and distributed collaborative computing, the agility and mobility of network resources, and the softwarization of network resource management. The individual network entities (microscopic level) of a SEN interact locally with each other in a distributed peer-to-peer fashion resulting in the evolving structure and functionality of the overall SEN system (macroscopic level). Designing individual entities’ simple behaviours that will result in the sophisticated organization and high performance of the overall SEN is critical. SEN embodies a special entity that resolves conflicts and manages the coordination among the individual network entities. The SEN’s conflict avoidance
and coordination management entity works on multi-levels spanning from single network domain to multiple operators and ecosystems.

Figure 2 shows the evolution engine of SEN. The engine cycle starts by collecting data, such as network status, data traffic, and mobility patterns, through users and network devices, sensors, and external sources (e.g., news and weather forecast). The massive collected data may go through some pre-processing procedures (e.g., cleaning, reductions, transformations). Different types of ML algorithms can be applied. SEN engine’s core utilizes both special pre-designed ML models that can be obtained from the SEN repository and adapted models that can be modified on the spot to meet new requirements. In the dynamic environment of wireless networks, fast online learning algorithms executed at the network edge and distributed among UEs will be necessary to provide fast intelligent and adaptive responses to delay-sensitive applications. Offline ML is important for prediction and planning purposes. Afterwards, the selected/designered ML model can be used to make automated and intelligent decisions, such as automatically allocating or retrieving resources, ordering a UAV-BS, forming a new temporary network, adjusting beamforming parameters, preparing for handoff, and offloading computations to fog/cloud computing. Moreover, a decision can be made to use a development tool from the repository (e.g., a special ML model, a coordination scheme, or a network component). Periodically, the network performance and user satisfaction need to be measured then the network can intelligently decide to perform a new cycle of self-evolution.

To cope with changes in the network environment, SEN has a development repository of new adopted technologies, agile and mobile resources, coordination schemes, network components, services, intelligent decision-making models, and specially designed ML algorithms. SEN performs a continuous examination, scanning, assessing and predicting changes in application/service requirements, users’ needs, and network status. When a need or a change is detected, SEN selectively obtains the suitable development tool from the repository and adaptively exploits it to meet the variable requirements. Basically, SEN has the characteristic of “autonomous driving networks”.

The distributed interaction of SEN entities eliminates the effect of single point of failure, and the system can repair or correct damages without external help. The combination of the adaptability of SENs with their distributed nature presents two major advantages: robustness against failure and scalability. The continuous evolution of SENs increases the reliability of the network. SENs can provide end-to-end network automation that is not limited to optimizing network configuration parameters, but can reach the level of automatically forming a temporary communications network (i.e., through mobile and agile BSs) to fulfill the demands of a specific area for a certain time. Through ML, SENs can enable automated SDN reprogramming, network function virtualization (NFV), and dynamic network slicing (NS) to match highly variable user demands and efficiently utilize resources.

III. OVERVIEW OF I-VHETNET ARCHITECTURE

The I-VHetNet architecture, shown in Figure 3, not only integrates the terrestrial-aerial-satellite networks, but it also incorporates intelligence and provides a computation and caching platform to enable multi-level edge computing. In future networks, BSs might not only be for communications, they might also be utilized for computation or storage. The distributed computing resources in I-VHetNet facilitate the application of ML algorithms. The SEN framework supports the intelligence and computational dimensions of I-VHetNet.

A. Game-Changing Components of I-VHetNet

a) UAV as a BS: UAV-BS concept was mentioned in 3GPP Release 17 documents TS22.125 and TS22.261 [5]. Under time and energy constraints of fast UAV-BS deployment, several tangled complex decisions must be made very fast, including load balancing, radio resource management, route management, and beamforming. An intelligent and automated management approach is necessary to enable the self-deployment of UAV-BSs, handle their fast mobility and handoffs, and manage the connections of the hundreds or possibly thousands of users that are served by the UAV-BS.

b) UAV as a User Equipment (UE): The use of UAV-UEs (e.g., cargo drones) is already supported through existing terrestrial networks [6]. The main future challenge is the scalability of existing solutions when the number of UAV-UEs reaches into the millions. Mobility management in a 3D scenario for such a huge number of UAVs will certainly be a big challenge. It is expected that SEN will play an important role in these setups through automating and optimizing the processes of radio resource management, and mobility management across networks and operators.
c) High Altitude Platform Station (HAPS) Systems: A HAPS will be a principal quasi-stationary network element in the aerial network. Current HAPS deployments target an altitude of 18-21 km with a coverage of a radius 50-100 km [7]. The HAPS has emerged as a viable aerial network component due to the evolution in communications technologies and the advances in solar panel efficiency, lightweight composite materials, autonomous avionics, and antennas [8]. With free-space optical (FSO) secure communications, several HAPS systems can form a powerful backbone network and enable an ultra low latency backhaul connectivity for UAVs and various aerial network elements. Manual or semi-automated management in such a complicated system will limit its capabilities, waste its resources, and increase its operational costs. Therefore, SEN automated management is vital for HAPS systems.

d) LEO Satellites: In the near future an immense number of low earth orbit (LEO) satellites are going to be orbiting the earth to provide global connectivity and Internet access to users everywhere. As a key player in our SEN I-VHetNet, satellite networks are self-controlled and self-managed with automated decision-making capabilities. This can be achieved by incorporating the SEN automated management in LEO satellite networks.

B. Distinctive Characteristics of I-VHetNet

a) Intelligence Dimension: Intelligence is necessary to support the concept of SEN in I-VHetNet. The highest and most powerful level of intelligence is executed in the cloud computing centers located in the core network. The middle level is at the edge/fog computing facilities near the users,
where fast and intelligent computation can be done. The third level is the level of UEs (e.g., autonomous vehicles and cargo drones), where such smart devices can collaborate among each other and with the edge computing nodes to achieve distributed intelligent learning and decision-making.

b) A Group of Self-Evolving Networks with Distributed and Intelligent Decision-Making: I-VHetNet consists of a group of SENs that collectively form a large integrated SEN, which can create, organize, control, manage, and sustain itself autonomously by using the evolution engine. This will create high adaptability to changes in the network environment and increase the scalability, robustness, and fault-tolerance. Such networks can be formed horizontally (i.e., within one of the three integrated layers) or vertically (across multiple integrated layers). SEN can automate the processes of SDN programming, NFV, and NS to make network softwarization more dynamic and intelligent to satisfy the needs of a highly variable communications environment.

c) Multi-Level Computing and Caching: I-VHetNet provides computational and caching capabilities at multiple levels to serve future applications (e.g., augmented reality) that require high computational capabilities. The cloud level provides the highest computational power and storage capacity. The network-edge level supports delay-sensitive applications through mobile-edge/fog computing. The lowest level is provided by managing the collaborative computing and resource sharing among UEs. The I-VHetNet computational and caching dimension not only supports user applications, it also supports the intelligent automation functionality in SENs. On the other hand, the SEN framework can automatically manage and self-allocate the required communications and computational resources to fulfill the constantly changing user demands. With the distributed computational resources in I-VHetNet, implementing distributed ML algorithms will be practical and feasible.

d) Dynamic, 3D, and Agile Topology: I-VHetNet integrates terrestrial, aerial, and spatial networks in a 3D topology where everything can move including BSs (e.g., UAV & satellite). As I-VHetNet consists of a group of SENs, this will allow forming, splitting, and slicing of networks based on changes in user demands. With the agility and flexibility of SENs, we do not have to over-engineer or excessively densify the terrestrial network to provide high throughput rates or temporary coverage, which are necessary only for a short time (often unpredictable). SEN evolving characteristic can play a significant role in managing the I-VHetNet’s resources and topology.

Fig. 3: Intelligent vertical heterogeneous network (I-VHetNet) architecture with distributed intelligence and computational capabilities. The terrestrial layer consists of the conventional BSs. UAVs, flying aircrafts, and high altitude platform station (HAPS) systems are the main components of aerial networks. UAVs can be used either as an aerial BS or as user equipment.
e) Seamless ConnectivityAnywhere, Anytime, and for Everything: I-VHetNet architecture extends the coverage of communications networks not only to the entire globe but also to the surrounding air and space. Through the SEN framework, seamless connectivity can be achieved by realizing full coverage and required communication capacity with optimized mobility management. In particular, satellites and HAP systems will play a significant role in solving the problem of coverage in areas where there is no network infrastructure (e.g., rural areas, offshore platforms, ships, submarines). In SEN, the mobility of resources and users can be intelligently managed to achieve seamless connectivity anywhere, anytime, and for everything.

IV. SELF-EVOLVEMENT ENABLERS IN FUTURE NETWORKS

A. Massive Volume of Data

Massive volumes of data will be generated from sensors, surveillance cameras, smart gadgets, vehicles, UAVs, HAP systems, and satellites. The collected data is the precious fuel of data analytics and ML algorithms. Such data can be used to reveal trends, hidden patterns, unseen correlations, and achieve automated decision making. It can also be used to continuously learn about user behaviour and enable the networks to proactively adapt to changes in the communications environment. However, data anonymization techniques are essential to maintain user privacy.

B. Softwarization Paving the Way for Intelligence

Softwarization is expected to bring the benefits of programmability into network management and control [9]. However, by using intelligent decisions obtained through ML algorithms to apply network softwarization, this moves the network control and management to the intelligentization dimension. For example, intelligent SDN can be redefined automatically and dynamically on the basis of intelligent decisions to adapt to changes in the communications environment. Similarly, NS can be done on the basis of future demands predictions. Moreover, the process of defining or programming the network using SDN, NS, or NFV can be automated through ML algorithms.

C. ML Science Advances

Currently, there are a number of powerful ML algorithms, such as deep neural network and reinforcement learning, which resemble the human brain learning process of trial and error. In addition, new ML algorithms are emerging such as meta learning and continual learning, where a dynamic ML model can be modified and adapted through re-configuring some parameters. Moreover, research is progressing on the concepts of learning how to learn and what to learn.

For resource-limited UEs, some simplified novel ML algorithms (e.g., compressed deep neural networks learning) have been proposed. FastGRNN and FastRNN are algorithms to implement recurrent neural networks (RNNs), and gated RNNs into tiny devices [10].

D. Edge and Fog Computing Capabilities

The computational power of edge/fog computing can be used to execute ML algorithms on behalf of resource-limited devices such as smart phones or sensors [11]. The SEN framework’s distributed and collaborative computing component can utilize the edge computing resources to realize the functionalities of SEN. In SEN, communications enable distributed intelligence and intelligence improves communications performance. Offloading computations to the network edge has many advantages. First, data and computations can be processed locally which reduces the response delay and enables real-time data-driven applications [12]. Second, offloading to the edge reduces traffic and congestion towards cloud data centers. Third, edge/fog computing supports mobility-aware applications as it considers user mobility. Fourth, as data do not have to travel through many nodes in the network, user privacy and data security are more preserved. Edge/fog computing can be performed at different levels of computational capabilities and locality by dedicated nodes or in a collaborative way through exploiting the aggregated UEs’ computational capabilities and distributed intelligence.

E. Collaborative Computing and Distributed ML

In big data centers, complex ML jobs are divided into small tasks that are executed in parallel on multiple virtual or physical machines. This makes the idea of collaborative computing [13] feasible by distributing the tasks of ML among a group of collaborating fog nodes or UEs. As a leading alternative to centralized ML algorithms, federated learning techniques can provide a platform to achieve distributed ML with high prediction accuracy in a privacy-preserving manner [14]. To realize the concept of distributed intelligence in SENs, the edge computing and the aggregated computational resources of UEs can be utilized to form a ”collaborative edge/fog cluster”, where data can be shared under privacy and security preserving techniques (e.g., federated learning). Since the resources in such clusters are distributed, reliable and fast communications among the participants is crucial.

V. ENVISIONED SCENARIOS OF SEN BASED ON I-VHetNet ARCHITECTURE

In this section, we present some scenarios to explain how the SEN framework can support I-VHetNet.

A. Intelligent Network Selection

Through SEN framework high load balancing across networks and BSs can be achieved by learning user demands and mobility patterns. SEN can make automated decisions of choosing the optimal serving cells, network, or even the network components and architectures that match the required services loading situation (e.g., choosing a flat architecture, an edge/cloud server, and a suitable core network parts, etc.). Using the network self-awareness information obtained through continuous learning of network’s status, I-VHetNet can utilize the SEN functionality to cluster users based on their required QoE, mobility patterns, and device capabilities,
Fig. 4: (a) Intelligent network selection for users A and B. As UEs might not be able to carry out such complicated intelligent decision-making procedure, SEN framework can autonomously make such a decision while considering all available networks, operators, and even ecosystems. (b) Based on intelligent prediction/detection, SEN framework can make automated decisions to extend network capacity by a HAPS (left), and extend network coverage by a temporary network of UAV-BSs (right). Such extensions can be achieved in a timely manner and for a certain duration in order to intelligently manage network resources. (c) Intelligent and dynamic beamforming for mobile network entities, where SEN framework can automatically adjust the formed beam through different technologies, domains, networks, and operators to adapt to the mobility of the user. (d) Distributed data offloading and computing towards three data centres with different computing capabilities and are accessible through one of the integrated networks (terrestrial, aerial, and satellites). In this scenario, SEN framework plays the role of managing the automated and optimized distribution based on network conditions and data sizes in order to minimize the overall offloading and computing delays while utilizing network resources efficiently. (e) A HAPS network as an aerial mini data center, where SEN will provide the automated management of the mini data centre and coordinate data offloading and processing with the ground data centre.
Fig. 5: (a) Data offloading and computing delays for 300 users. The highest delays are when offloading the data for computing in the farthest data centre (3) which is reachable through satellites only. In the integrated networks of I-VHetNet, SEN framework optimally distributes the data and computation offloading among the three data centres and achieves the lowest delays (I-VHetNet SEN). (b) Data offloading and computing delays for 3000 users. Compared to Fig. 5 (a), it is obvious that the terrestrial data centre (1) is overloaded, which results in extra delays (even higher than data centre (2) that is reachable through HAPS). This is because SON cannot optimally utilize the resources across different networks and ecosystems. Although the number of users has increased by a factor of 10, SEN manages to achieve the lowest delays.

and then intelligently make decisions to provide the best communications network selection. SEN can play significant role in optimizing the handoff target and timing to guarantee seamless connection. Figure 4a illustrates this scenario.

B. Extending Network Capacity/Coverage

I-VHetNet consists of a group of SENs. The massive collected network data can be utilized to predict future network events, whereby proactive actions can be performed to avoid delays or network failures. In addition, with advanced ML, SENs have the ability to learn new environments and deal with unprecedented network situations. Thus, the network has the ability to extend its coverage or capacity by using mobile BSs, splitting itself into two or more networks, merging with other networks, and/or forming a new network. For example, with deep learning, the spatial and temporal wireless traffic patterns can be used to match the network’s capacity to user demands by establishing a new temporary network through collaborative mobile BSs without over-engineering the network’s physical resources, as shown in Figure 4b.

C. Intelligent Beamforming

In I-VHetNet, communications will depend heavily on beamforming in order to mitigate interference [13]. The SEN framework can be used to optimize beamforming parameters and achieve dynamic beamsteering across different networks, and operators. As a SEN, multiple coordinated HAPS systems or UAV-BSs in I-VHetNet, which are equipped with multi-antenna arrays, can form distributed MIMO-network. Through intelligent and distributed control, and with conflict avoidance entity of SEN extremely precise beams can be created that can track the user mobility while limiting the interference, as depicted in Figure 4c. To accurately change the beam configuration based on changes in the communications network and user mobility, reinforcement learning or continual learning approaches can help incorporate intelligence in sequential decision-making processes such as these.

D. Distributed Data Offloading and Computation through Integrated Networks

Through the intelligent classification of the various requirements of different services, the SEN framework can optimally make decisions to distributed data offloading and computing across several networks, operators, and even ecosystems. For example, Figure 4d describes the scenario of having three data centres, where the first one (1) has the lowest computational capability and it is accessible through terrestrial networks, the second one (2) has better computational capabilities but it is
E. Aerial Mini Data Centers

HAPS systems equipped with powerful processors and connected with high-speed FSO links may collectively form a mini aerial data center and be an aerial network intelligence enabler, as illustrated in Figure 4e. Through the distributed and collaborative computing entity of SEN framework, the self-managed aerial data centers can provide near-user computation services for aerial networks users (e.g., drones) by allowing aerial network elements with limited resources to offload their intelligent algorithms computations. Analyzing data in the sky will reduce response delays and decrease the burden on the aerial-to-ground communications links, which can be easily disrupted by the fast speed of aerial network elements. Due to its relatively large footprint, a HAPS can collect data from large portions of the aerial network to use it in supporting the self-evolution of aerial networks. These data centers can also provide a backup computational facility in emergency scenarios.

VI. CHALLENGES AND RESEARCH DIRECTIONS

Incorporating intelligence in future networks and realizing the concept of SEN faces many challenges that require intensive research work. In this section we discuss some of the most important challenges in the following points:

- **Real-time and online learning algorithms**: Most existing ML algorithms require relatively long convergence times. However, in future communication networks the environment may change rapidly and many applications may require fast decision-making that adapt to changes in the network. Online and continual learning algorithms should be further enhanced and adapted to suit the future integrated network environment.

- **Learning what to learn and how to learn**: In many situations, a given node in a network does not need to learn the full network environment. Learning within a certain scope and time frame is sufficient in many cases. Choosing an appropriate data scope and duration is important to avoid learning and processing unnecessary data. This issue is quite important for network nodes with high mobility or limited processing resources. In current ML applications this is done in a manual way by the developers or engineers. However, to realize the concept of SEN, emerging meta learning, continual learning and the concept learning how to learn need to be adopted and enhanced to adapt to the dynamic environment. Learning how to learn and what to learn should be done in an automated way, which needs intensive research work.

- **Information sharing and learning across networks, operators, and ecosystems**: To implement the SEN framework, new policies are required to control data sharing and collection across different networks, operators domains, and ecosystems. Thus, the networks and communications community should invest in developing novel ML algorithms that are designed for distributed learning scenarios. It would be a major enhancement to extend federated learning concept to work on different levels and scales. Privacy and security is a main concern in this area. In addition, new schemes are needed to handle the emerging issues such as data ownership rights, data credibility, data trading, and data pricing while maintaining users’ privacy and rights.

- **Intelligent and standardized conflict resolution algorithms**: In the environment of SENs, conflicts might arise among entities with contradicting objectives (e.g., minimizing delays and sharing resources). In addition, SENs will involve several operators and each one of them has the goal of maximizing his own profits, which might result in greedy behavior among operators where the user might pay the price. Nevertheless, resolving conflicts among different operators, networks, or ecosystems with heterogeneous technologies and different operational policies is a very complex task. In this domain, intelligent conflict resolution algorithms need to be developed which can mimic the human way of thinking in similar situations. In addition, standardised conflict resolution algorithms are also necessary to ensure compatibility between different systems.

VII. SUMMARY

Providing extra resources in future networks without intelligent and automated management may not fulfill the requirements of the emerging applications and expected QoS levels. Efficient integration of terrestrial, aerial, and satellite networks of the future will necessitate intelligent, automated, adaptive, and real-time control, optimization, and management. To this end, we introduced the self-evolving networks (SENs) framework. Empowered with AI/ML, SEN framework can make intelligent, adaptive, and automated decisions:

- to manage heterogeneous network dynamically and intelligently in a distributed manner across different domains, networks, and ecosystems;
- to resolve conflicts and manage coordination among several automated network entities;
- to satisfy the QoE requirements of an enormous number of a broad range of UEs (including IoT devices);
- to handle the high levels of heterogeneity, agility, and 3D mobility of both UEs and BSs; and
- to utilize the UE assets (integrated with those of the network) in the provision of communications and computation services.
We constructed five prominent I-VHetNet communications and computation scenarios, which model several aspects of SENs. In addition, we listed the leading enablers and the associated challenges.

REFERENCES

[1] M. Alzenad and H. Yanikomeroglu, “Coverage and rate analysis for vertical heterogeneous networks (VHetNets),” IEEE Transactions on Wireless Communications, vol. 18, no. 12, pp. 5643–5657, Dec. 2019.

[2] L. Zhang and N. Ansari, “A framework for 5G networks with in-band full-duplex enabled drone-mounted base-stations,” IEEE Wireless Communications, vol. 26, no. 5, pp. 121–127, Feb. 2019.

[3] A. Mestres, A. Rodriguez-Natal, J. Carner, P. Barlet-Ros, E. Alarcón, M. Solé, V. Muntés-Mulero, D. Meyer, S. Burkai, M. J. Hibbett et al., “Knowledge-defined networking,” ACM SIGCOMM Computer Communication Review, vol. 47, no. 3, pp. 2–10, 2017.

[4] J. Moysen and L. Giupponi, “From 4G to 5G: Self-organized network management meets machine learning,” Computer Communications, vol. 129, pp. 248–268, Sep. 2018.

[5] 3GPP, “Unmanned Aerial Systems over 5G,” 3rd Generation Partnership Project (3GPP), Tech. Rep., Nov. 2019. [Online]. Available: https://www.3gpp.org/technologies/acronyms/2009-unmanned-aerial-systems-over-5g

[6] I. Bor-Yaliniz, M. Salem, G. Senerath, and H. Yanikomeroglu, “Is 5G ready for drones: A look into contemporary and prospective wireless networks from a standardization perspective,” IEEE Wireless Communications, vol. 26, no. 1, pp. 18–27, Feb. 2019.

[7] T. Tozer and D. Grace, “High-altitude platforms for wireless communications,” Electronics & Communication Engineering Journal, vol. 13, no. 3, pp. 127–137, Jun. 2001.

[8] G. Kurt, M. G. Khoshkhohlgh, S. Alfattani, A. Ibrahim, T. S. Darwish, M. S. Alam, H. Yanikomeroglu, and A. Yongacoglu, “A vision and framework for the high altitude platform station (HAPS) networks of the future,” arXiv preprint arXiv:2007.15088, 2020.

[9] K. Wang, Y. Wang, D. Zeng, and S. Guo, “An SDN-based architecture for next-generation wireless networks,” IEEE Wireless Communications, vol. 24, no. 1, pp. 25–31, Feb. 2017.

[10] A. Kusupati, M. Singh, K. Bhatia, A. Kumar, P. Jain, and M. Varma, “FastGRNN: A fast, accurate, stable and tiny kilobyte sized gated recurrent neural network,” in Advances in Neural Information Processing Systems (NIPS), 2018, pp. 9017–9028.

[11] T. S. J. Darwish and K. A. Bakar, “Fog based intelligent transportation big data analytics in the Internet of vehicles environment: motivations, architecture, challenges, and critical issues,” IEEE Access, vol. 6, pp. 15 679–15 701, 2018.

[12] S. Chen, P. Gong, B. Wang, A. Anpalagan, M. Guizani, and C. Yang, “Edge AI for heterogeneous and massive IoT networks,” in IEEE 19th International Conference on Communication Technology (ICCT), 2019, pp. 350–355.

[13] H. Lee, J. Lee, Y. C. Lee, H. Han, and S. Kang, “Mobile collaborative computing on the fly,” Pervasive and Mobile Computing, vol. 58, pp. 1–19, Aug. 2019.

[14] Z. Zhao, C. Feng, H. H. Yang, and X. Luo, “Federated-learning-enabled intelligent fog radio access networks: Fundamental theory, key techniques, and future trends,” IEEE Wireless Communications, vol. 27, no. 2, pp. 22–28, May 2020.

[15] H. Vaezy, M. S. H. Abad, O. Ercelebi, H. Yanikomeroglu, M. J. Omidi, and M. M. Naghsh, “Beamforming for maximal coverage in mmwave drones: A reinforcement learning approach,” IEEE Communications Letters, vol. 24, no. 5, pp. 1033–1037, May 2020.