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Architecture for Scalable, Self-*, human-centric, Intelligent, Secure, and Tactile next generation IoT

ASSIST-IoT Technical Report #1

Reviewing SDN adoption strategies for Next Generation Internet of Things networks

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Abstract. As Internet of Things networks grow in heterogeneity and complexity, the associated industry needs to improve the performance of traditional network deployments. One of the main relevant evolutions on network architectures is depicted by the remote control of the forwarding state of the equipment. The advance here consists in having the data plane managed by a remotely controlled plane decoupled from the former, enabling to program the behavior of a network without being tied to inflexible rules and conditions. To support this network evolution, Software-Defined Networking (SDN) allows programmability as the main role in improving resource efficiency and increasing service reliability and security. The analysis conducted in this paper aims at reviewing the different adoption strategies to effectively deploy SDN-enabled Next Generation IoT systems, analyzing in detail the variations found between the types of access network layers, and the SDN applications that can be carried out. The analysis ranges from basic deployments (where the concerns are specific to the direct connection end devices-network) to complex, multi-application advanced ones (where alternative configuration and layouts come into play). The paper concludes with the presentation of the approach taken in the project ASSIST-IoT, that will apply the previous knowledge towards the definition of a blueprint architecture for the Next Generation Internet of Things.

Keywords: SDN, IoT, Next Generation Networks, adoption strategies, RAN, SD-WAN, cellular networks, mesh.

1 Context

1.1 Next Generation Internet of Things

According to relevant sources, around 28 million of smart devices will be connected to the Internet by the end of 2021, while generic end-devices and actuators may reach the dizzying figure of 55 billion [1] by 2025. This ever-increasing number of Internet of Things (IoT) contributors is forcing the sector to face new challenges. As data grow in size and heterogeneity, issues of interoperability and scalability become a rising concern. Moreover, advances in complementary fields like Big Data Analytics, Artificial Intelligence, Edge Computing, 5G or Robotics are converging to compose what is called the Next Generation IoT (NGIoT). This concept converts the IoT landscape into a portfolio of all-encompassing digital transformation enablers, supporting the Next Generation Internet (NGI) vision. Additional traits will have then to be covered by the future IoT deployments, such as near-real-time reaction, automatic decision making, semi-autonomy or human-centricity [2]. Up to now, available IoT system approaches forwarded and handled data through the network following a set of design criteria, lacking capabilities to tackle the aforementioned requirements. Those traditional IoT deployment networks are based on dedicated hardware and software, which are limited to the rules inherited from classic Internet solutions. The network supporting this communication is also static and costly, relying on fixed-function devices (switches, routers) which seem no longer able to face those challenges [3]. Therefore, the need of dynamic networking is obvious. To respond to that need, the programmable networks were linked to the IoT.

1.2 Introduction to programmable networks

One of the main historical evolutions on network architectures is depicted by the remote control of the forwarding state of the equipment. "Programmable networks" have been proposed to decouple hardware and control decisions and to simplify network management without being tied to inflexible rules and conditions.

A packet arrives at the controller including the flow. The controller knows the topology of the global network and performs route calculation for allowed flows. Ethane [4] was considered as the predecessor to OpenFlow, which is currently the reference technology. Initially proposed by Stanford University, and now standardized by the Open Networking Foundation (ONF), the structure of OpenFlow and the description of SDN approach was made. Controller helps applications (Northbound APIs) to reach their purpose by controlling SDN switches (Southbound APIs) through forwarding tables. Network adjusts itself to users' needs and, using controller and APIs, network managers can easily control the network automatically by adding new features to the control plane without making changes in the data plane [5].

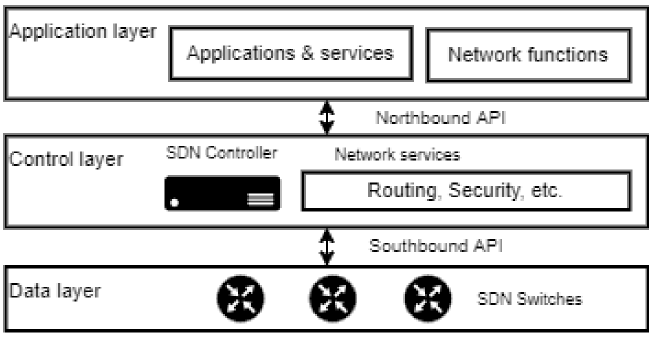

Fig. 1. OpenFlow SDN architecture

2 Software Defined Networks (SDN) structure

2.1 The core element: SDN controller

Following the philosophy of the "programmable networks", **the intelligence in an SDN network is moved to the controller**, allowing data layer distribution to favor the exchange of data between different points. A controller is a software installed in the control layer of an SDN-enabled equipment. It has a general view of the network topology, performing traffic flow actions dictated by application policies among the devices in the data plane.

A wide variety of controllers have been designed by the Industry based on different languages (C, C ++, Java, Java Script, Python, etc.) to support state consistency, scalability, flexibility, and security [6], allowing efficient memory allocation that improves performance, as well as cross-platform compatibility. Controllers can be classified according to their support on physically and logically distributed networks. This requirement is crucial when adopting SDN, as some controllers support different control plane architectures, and use its techniques to communicate with other controllers.

2.2 Architecture distribution

SDN deployments are governed by controllers. However, there is not a fixed layout of the network that should be followed in all cases. Depending on the needs or capabilities, various types of architecture distribution might be recommended. In this chapter, a succinct explanation of those (accompanied by some real examples) is provided.

Physically Centralized. In a physically centralized control plane, a single controller is needed for the entire network. While recommended for networks small enough to be in one place, it does not meet the different requirements of large-scale, multi-location network deployments.

Physically Distributed. When deploying complex, large networks, a different approach is needed. Scalability problems such as Single Point of Failure, bottlenecks, etc. require a physically distributed control plane [7]. The main characteristics of this philosophy are the following: (i) a single controller handles horizontal slices of the network into multiple areas with a subset of SDN switches, (ii) a hierarchical SDN control architecture with a vertically partitioned control plane into multiple layers.

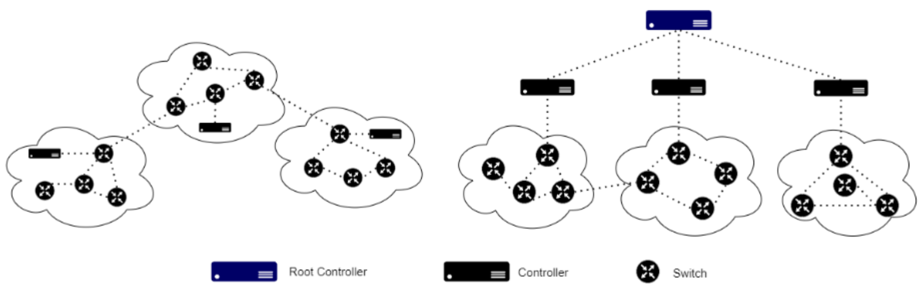

Fig. 2. Flat/Hierarchical controllers' distribution

Besides, within the physically distributed architectures, two different configurations can be distinguished: *Logically centralized*: In a logically centralized approach, a set of controllers with the same view of the network and the same shared database collaborate to manage the physically distributed switches [7]. Different techniques such as state replication (e.g., ONIX [8]) and event replication (e.g., HyperFlow [9]) are used to achieve controller state redundancy, allowing control plane scalability. *Logically distributed*. Other implementations (such as DISCO [10]) consider extending the SDN paradigm to cross-domain networks while remaining compatible with their distributed implementation, implying logically distributed control. In this approach, each domain is managed by its controller and can share only some certain information to achieve some services such as topology view.

3 SDN adoption strategies

First, the communication technologies, end devices, and how are connected to an SDN network must be selected. Later, analysis about the data generated from the devices may require adapting data packets to be properly transmitted. The results of the two previous reflections would contribute to the design of the **basic network deployment**. According to our own definition, a basic network deployment is formulated as one where only the connection between end devices, associated gateway and SDN controller must be put in place: (i) IoT communication technologies, (ii) WiFi deployments and (iii) radio networks. Building atop the basic deployment, some variations may be implemented to achieve new possibilities in **more advanced network deployments** that include devices configuration, alternative technologies, or a variety of physical and logical systems distribution. Furthermore, some proposals base their development on the computing resources location (e.g., cloud computing) to allocate the network equipment: (i) WAN-powered networks, (ii) mesh networks and (iii) cellular networks.

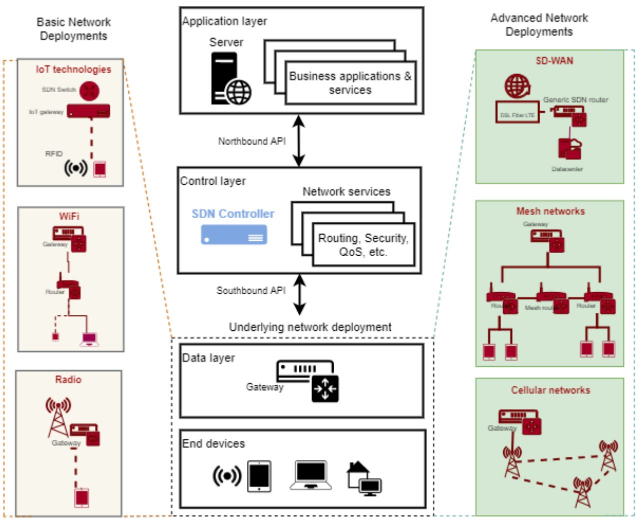

Fig. 3. SDN adoption strategies

3.1 Strategies in basic network deployments

IoT access technologies. Short range and low power consumption (e.g., BLE [11] or Zigbee [12]) as well as wide area coverage (e.g., LoRaWAN [13], Sigfox [14] or NB-IoT [15]) are the main wireless technologies considered for IoT today as they allow to scale efficiently, manage resources and optimize operations [16]. To complete the communication between the IoT sensor/device and the controller, IoT gateways communicate with SDN switches accessing to different IoT devices through the control data plane interface form the infrastructure layer. The operating system on the control plane provides centralized control and visibility of different IoT services, achieving network functions such as routing, access control in firewalls, secure tunneling between the IoT gateway and the utility server in the IPsec protocol, and QoS. Nodes should find their way towards a Sink, the network element that receives control packets before leaving the Wireless Sensor Network (WSN) and reaching the controller [17].

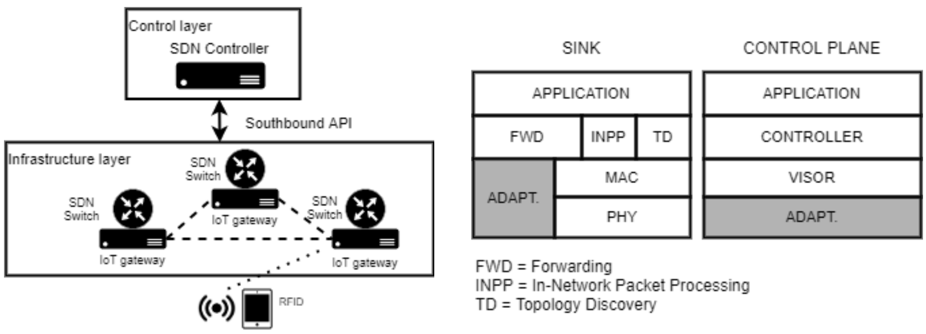

Fig. 4. Left: IoT devices and sensors communication in SDN. Right: IoT Packet adaptation

Some IoT-based wireless sensor networks proposals focus on the adaptation of the information flowing from the sensor into the SDN controller:

SDN-WISE [18]: The middle layer is managed by a visor that collects sensor/device packets. An adaptation layer is needed to perform translation between the sensor node and the Visor. The controller implements topology management, building the overall network topology by collecting topology discovery reports from each sensor node. A WISE-Visor allows multiple controllers to run on the same data plane network using abstraction and virtualization. *WSN-SDN* [19] aims to develop an architecture consisting of a Base Station (BS) and several sensor nodes. SDN controller operates on BS taking routing decision. Sensor nodes contain a flow table as in the SDN concept which is populated by SDN controller.

In **radio networks,** a physical intervention is needed to deploy an effective SDN ecosystem. SDN can be applied abstracting the Radio Access Network (RAN) by a centralized control plane, while the resource allocation is enabled by a big base station. The controller allocates resources in the domain of frequency, time and space slot [20].

In this regard, several proposals have been analyzed as well. *O-RAN* [21] aims to be more intelligent, open, virtualized, and fully interoperable among mobile network operators. The architecture focuses on developing open-source RAN AI empowered, with modularity and operability capabilities which is envisioned as next generation RAN. *SD-RAN* is ONF's new exemplary platform for 3GPP compliant software-defined RAN that is consistent with O-RAN architecture [22]. SD-RAN creates open-source components for the mobile RAN space, being cloud native and testing O-RAN compatible open-source components. *Hybrid SDN-SDR* [23] provides cross-layer combination of SDN and Software-Defined Radio (SDR) for exploiting frequency spectrum and link information in the 5G network. The cross-layer controller is used to request frequency spread spectrum and make the decision to flow traffic, granting authorized access to a better mobile band. *SoftAir* [24] proposes to convert the whole data plate into SD: software-defined radio access network (SD-RAN) and software-defined core network (SD-CN). Mobility-aware control traffic balancing, resource-efficient network virtualization, and distributed and collaborative traffic classifier are allowed by implementing a set of SD-BSs, while the SD-CN is composed of a collection of SD-switches.

WiFi. Home networks have a high use of multimedia rich entertainment applications that stream video and audio and require low-level configuration to implement different controls [25]. Some of these applications have real-time limitations, requiring high bandwidth and low latency. With SDN, a centralized controller can offer better resource allocation and management to avoid congestion and distribute the load among routers, while providing better resource utilization abstracting computation [20]. The most relevant approach found in the literature is *ODIN* [26], which enables network operators to deploy WLAN services as network applications. The master runs as an application on the OpenFlow controller, controls the agents, and updates the forwarding table of access points (APs) and switches, whereas the agents run on the APs and collect information about the clients.

3.2 Strategies in advanced network deployments

SD-WAN allows dynamic bandwidth configuration, routing, and traffic efficiency to deploy services in scattered places. The advantage over traditional WAN is that a common management platform defines the policy once and it applies to all devices. SD-WAN uses a layered approach with abstraction in its architecture, made up a physical or virtual SD-WAN edge, WAN gateway and SDN controller. The orchestration plane acts as a first layer of security to analyze third-party devices, asking credentials to the devices and providing the address of the controller. Therefore, the edge device becomes part of the management fabric. A subscriber web portal can be added to create or modify client services [27].

Varied SDN applications have been proposed in data center networks (DCNs) to improve and modify their performance, including changes in DCN infrastructure and virtualization of data-center LANs and WANs.

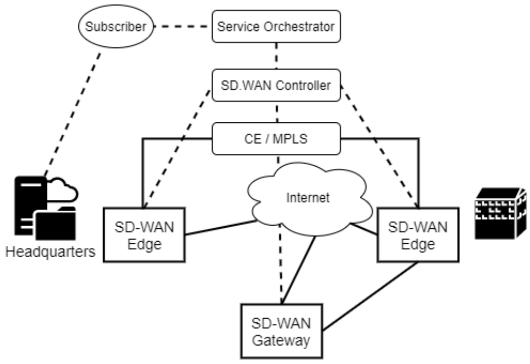

Fig. 5. SD-WAN layered approach

Google B4 [28] is a private WAN that connects Google's data centers across the planet, with massive bandwidth requirements. Each B4 site consists of multiple switches linked to remote sites. SDN improves elastic demand management that seeks to maximize average bandwidth. A B4 SDN architecture approach can be logically viewed in three layers that provide full control over the edge servers and network, supporting distributed routing protocols, maximizing interoperability and scalability. *Microsoft SWAN* [29] sets its main resources in distributed data centers all over the world. SWAN project is a SD-WAN implementation for inter-data center networks that centrally controls traffic and re-configures the network data plane to match the current demand. SWAN routes the update of the switch in a congestion-free manner by taking advantage of a small amount of scratch power on the links.

Mesh networks. The proliferation of automation systems introduces additional traffic with stringent Quality of Service and Experience requirements [30]. A Wireless Mesh Network (WMN) solves this issue by setting a local network topology structure of wireless routers in which all network components can connect directly, dynamically, without hierarchy usage, to provide Internet access to clients. Due to the congestion that can arise from the limited number of routers acting as gateways, efficient allocation and management of resources and routing is of paramount importance. For doing so, traditional routing protocols cannot take full advantage of the multiple paths between the source node and the destination node [31].

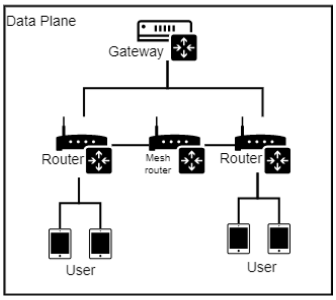

Fig. 6. Mesh network approach

In this sense, *SDNMesh* [32] is an SDN based routing architecture that combines SDN with WMN to allow mesh networks to meet user requirements with several resources, coverage, and scalable high bandwidth capability. SDNMesh bases its routing on two phases, where the first phase finds the initial route from the controller to the switches that may be inefficient in terms of delay, and the second phase optimizes those routes. This approach helps to find the routes between SDN switches.

In **Cellular networks,** BSs connect to unmodified User Equipment (UE) using existing protocols for managing mobility, sessions, and authentication that are implemented in control plane. The UE retains a single IP address as it moves between BSs in the same cellular core. The controller should be able to express policy in terms of subscriber attributes, rather than IP addresses or physical locations, as captured in a subscriber information base. Different implementations change how BSs communicate with the core network, by having them coordinating the controller to enforce service policies. Some existing proposals are:

Cellular SDN [33] architecture enables operators to simplify network management and control, allowing the creation of new services, in a flexible, open and programmable manner. Cellular SDN expands SDN model by considering an additional functional layer named “the knowledge layer” that allows the Managed Service Provider (MSP) to gain insights into the intelligent vision of its network and the users environment. *SoftCell* [34] enables operators to direct traffic based on subscriber attributes and applications. Since most traffic is originated from mobile devices, SoftCell performs detailed packet classification at access switches, alongside base stations, where software switches can easily handle status and bandwidth requirements.

Other. As mentioned, SDN deployments can also be designed considering computing needs or performance. For instance, in *large-scale data centers* (DCs), the growth of Virtual Machines (VMs), puts programmable networks in the center of the discussion towards improving infrastructure performance and energy consumption. SDN adds a virtualization layer to the architecture of the cloud providers so that the network can manage the tenants according to their demands and the controller can provision a new device that is added to the network and allow it to receive the policy when it appears online. Some solutions can be found in the literature to mitigate the interconnection challenges in a cloud DCN, or to facilitate live and offline VM migration, in east-west connectivity between data centers. In *optical networks*, the lack of compatibility between different equipment uncovers the need of improved control and management. SDN allows, there, efficient provision of technology-independent and unified control when treating data traffic as flows. The ONF combined SDN and the OpenFlow standard applications towards this goal [35]. Other SDN deployments, for instance, *Industrial* IoT [36] and *Smart Grid* [37] require more resource or bandwidth in unpredictable situations, subject to traffic profiles and application types. When an application request is made, infrastructure layer allocates resources to allow data forwarding. The adaptations allow the data layer to monitor local information so the data path management can be estimated locally at this layer using node-to-node negotiations in real-time.

4 ASSIST-IoT challenges and approach

ASSIST-IoT [38] is a novel, H2020-funded project which aims at developing a new architectural approach to future NGIoT deployments. ASSIST-IoT plans to advance the state of the art in several IoT-related field such as **distributed smart networking** components, decentralized security and privacy exploiting distributed ledger technologies as well as smart distributed AI enablers and human-centric tools and interfaces.

With regards to the smart networking (based on the technologies analyzed in this paper), ASSIST-IoT pretends to leverage SDN to **implement an access-network agnostic approach,** leveraging the programmability of switches and routers throughout the network to allow sensitive data to travel securely through public open equipment. Besides, ASSIST-IoT will build atop this smart networking trait to embed AI services supporting network self-configuration (as part of self-management) and management to make the network (semi-)autonomous. Technologically, ASSIST-IoT plans to develop an orchestrator based on current open-source contributions to be extended to fulfil network services that deployments of such characteristics may need.

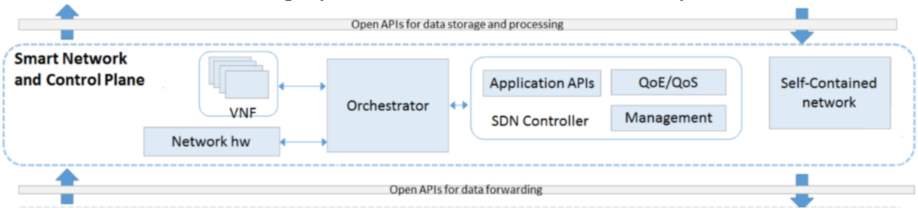

Fig. 7. ASSIST-IoT SDN innovation schema

For doing so, ASSIST-IoT will need to consider all the SDN adoption strategies outlined in this paper as a wide variety of underlying network deployments are expected in the targeted scenarios. Therefore, the design of the smart networking components in the project will need to foresee various approaches driving towards an access-network agnostic deployment in a seamless way to the human end-user.

5 Conclusions

In this paper we have observed differences in SDN implementation depending on the type of deployment. Advanced SDN controllers are aimed at covering situations that require great heterogeneity of devices and complex geographic distribution. For implementing SDN, not only communication technology must be considered, but also the distribution of access points, the content of data packets or the network requirements. Although it is relatively recent, it is a very promising technology, whose high degree of maturity have generated interesting initiatives and projects that are being developed and implemented nowadays. ASSIST-IoT is intended to benefit from SDN advantages and to include it as a key: maximizing its compatibility with all kinds of devices and distributions as seen in this paper and go further by including artificial intelligence to optimize resources and data transmission. Future publications will reflect the work of ASSIST-IoT in the implementation of SDN.

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