Towards a 6G System Architecture: Learnings from IEEE 1930.1 and IEEE P2061

Pranav Jha*, Rashmi Kamran*, Abhay Karandikar*†
*Department of Electrical Engineering, Indian Institute of Technology Bombay, India
†Director, Indian Institute of Technology Kanpur, India

***Abstract*—Mobile communications technology has seen significant evolution in the last few decades, the Third Generation Partnership Project (3GPP) 5th Generation System (5GS) is the latest addition to this continually advancing domain. While the 3GPP 5GS is being deployed today; the technological evolution continues with research, development and standardization activities towards the next generation mobile communications system. Every generation of mobile technology makes enhancements to radio access capabilities as well as network architecture. A few architectural advancements brought in by the 5GS are control and user plane separation, existence of a converged core and service based architecture. Even though the 5GS has undertaken many architectural improvements, it has certain limitations too, such as, complexity of features like dual-connectivity, or uniform handling of use cases with limited consideration for their diversity or complex interaction between access and the core, which may not be desirable for use cases like captive networks and rural broadband scenario. In this article, we discuss a few novel design concepts recently proposed as part of an IEEE standard 1930.1 and an ongoing standardization project IEEE P2061. These concepts have the potential to address some of the limitations of the 5GS and play important roles in the future mobile communication systems. We also provide an outline of the upcoming 6th Generation System (6GS) architecture, based on the leanings from IEEE 1930.1 and IEEE P2061 standards.**

***Index Terms*—6G networks, Cellular architecture, Software defined networking, Multiple radio access technologies.**

I. INTRODUCTION

THERE has been a tremendous growth in the cellular network deployment as well as in the number of cellular subscriptions globally in the last couple of decades. Concomitant with the huge growth of the cellular connectivity, the mobile data consumption has also grown at an exorbitant pace globally. For example, mobile data traffic in China, India (including Nepal and Bhutan), Western Europe and North America in year 2020 was 15, 9.5, 4.2 and 3.9 exabytes (EB) per month which increased to 20, 13, 5.8 and 4.8 EB per month within a year, respectively [1]. Globally this figure stood at 67 EB per month in 2021 [1]. Some of the factors to drive the growth of mobile data are increased usage of smartphones, devices with enhanced capabilities, ease of usage, appearance of a variety of data-intensive applications and an improved cellular network performance. An important factor behind the growth of mobile data traffic specific to certain geographical regions (such as India and many African countries) is also limited deployment of fixed-line networks, triggering the usage of cellular network as the primary broadband access. In order to visualize the enormous growth of mobile data traffic in future, we present an estimate for data traffic demand by 2030 in India based on the information provided in [2].

By 2030, India will likely have a population of more than 1400 million; assuming every household to have four persons on an average, the country may have 350 million households. It can safely be assumed that most households (and users) will use cellular connectivity for broadband access since there is limited deployment of fixed-line infrastructure in the country [3]. Considering the ubiquitous cellular data access, even a rough estimate indicates huge consumption of mobile data by 2030, when the next generation mobile networks are expected to be available. For example, with the consumption of mobile data at a modest rate of 5 Mbps per household along with a contention ratio of 10:1, the total mobile data traffic in the country would be close to 57 EB per month by 2030. The estimated figure is corroborated by other forecasts too. For example, the Ericsson Mobility Report June 2022 [1] predicts mobile data traffic of 49 EB per month for India in year 2027 itself. The report predicts a consumption of 282 EB/month globally in 2027. It has also been observed that the actual data volume is typically higher than forecasts [1].

In existing 3rd generation partnership project (3GPP) Fifth Generation system (5GS), a significant amount of signaling traffic is mediated to a centralized core network (CN) involving complex interaction between network functions. Due to potential scalability constraints of the CN control plane [4], the 5GS may find it difficult to scale to transport the huge traffic forecasted in the preceeding paragraph. Another issue with the 5GS is its uniform handling of use cases, which may not be an optimal strategy to support diverse use cases, e.g., rural broadband access may benefit from reducing its dependency on CN as opposed to a urban vehicular user [5]. Considering these observations, a rethink on the architecture for the 6G system (6GS) may be required.

This article reviews the existing 3GPP 5GS architecture especially access network (AN) along with some of its limitations with respect to scalability and flexibility to handle future requirements. Further, the article provides an overview of the architectures as proposed in IEEE 1930.1 (standard approved in 2022 [6]) and IEEE P2061 (ongoing standardization project [7]), and how they are able to address the limitations of the 5GS architecture. Based on the learnings from IEEE 1930.1 and IEEE P2061, we outline a set of key requirements and design guidelines for future mobile networks. The article also sketches an architecture for the 6GS AN utilizing the concepts from IEEE 1930.1 and IEEE P2061.

One of the authors, Mr. Pranav Jha is the working group chair of IEEE 1930.1 and IEEE P2061.

II. BACKGROUND

3GPP 5GS is the most advanced mobile communications system today. Key characteristics of the 5GS architecture along with some of its limitations are discussed in the following subsections.

A. Monolithic architecture

All existing cellular networks including the 5G network comprise a distributed (radio) access network ((R)AN) and a centralized CN with fixed distribution of functionality between them. In order to serve a user, extensive coordination between RAN and CN takes place. However, complex and expansive RAN-CN interaction adds delay to the service delivery and may also put scalability constraints on the network. The architecture is also inflexible as it does not allow for differentiated handling of use cases.

Remark: *Core network is an integral part of existing mobile networks. It is primarily needed to support user mobility, authentication, subscription and billing among other requirements. However, with mobile networks becoming ubiquitous and supporting a diverse set of scenarios, extensive and predetermined coordination between RAN and CN for every use case may neither be necessary nor optimal. We have discussed rural broadband use case earlier [5], similarly 5G-based captive networks may also gain from the removal of complex CN elements and placing a few mandatory ones in the edge along with other RAN elements.*

Hence, a way forward would be to have a flexible architecture with reduced dependency of RAN on the core and dynamic placement of network functions across RAN (edge) and core. Such an architecture may allow for differentiated treatment of services, if needed and likely to be scalable viz-a-viz existing architecture.

B. Multi-RAT heterogeneous network

5GS defines a converged core, which treats diverse access technologies (such as 5G-new radio (NR), Long Term Evolution (LTE), WiFi) in a uniform manner. This trend towards heterogeneous networks is expected to accelerate further in future with integration of additional radio access technologies (RATs) such as terahertz access, satellite access and digital terrestrial broadcast access technologies. Even though many of these access technologies bring their own specific capabilities, RAN functions across RATs may possess significant commonality. For example, most RATs need to support the following functionalities, some of which may be common across RATs:

- Physical communication and medium access control (MAC) over wireless medium,
- Communications security (ciphering and integrity protection) over wireless medium,
- Link layer adaptation and control over wireless medium,
- Flow optimization over wireless medium, e.g., Internet protocol (IP) header compression,
- Inter-working support with core etc.

Hence, it is possible to have greater harmonization across RATs through utilization of common functions within RAN itself. However, it is not supported in the existing 5GS where all RATs exist independent of each other at RAN level.

C. Dis-aggregated RAN

A high-level view of the existing 3GPP 5G RAN architecture is shown in Fig. 1 [8]. The RAN gNodeB (gNB) function is dis-aggregated into distributed units (DU) and a centralized unit (CU), interacting through the F1-C and F1-U interfaces. Further, the gNB-CU is divided into gNB-CU control plane (CP) and gNB-CU user plane (UP) by following software defined networking (SDN) paradigm. While the 5GS supports dis-aggregation, there is a scope for further distribution of functionality into more granular functions in RAN. RAN user plane functions, e.g., gNB-DU and gNB-CU-UP of 5G-NR RAT can potentially be dis-aggregated further, which may bring enhanced scalability to the network. Many of these granular RAN functions, e.g., “security” or “core network interworking” may be common and used across RATs. These granular data plane functions can be controlled by a unified multi-RAT RAN controller, enabling an integration of diverse RATs within RAN itself, which is not possible in the existing 5GS.

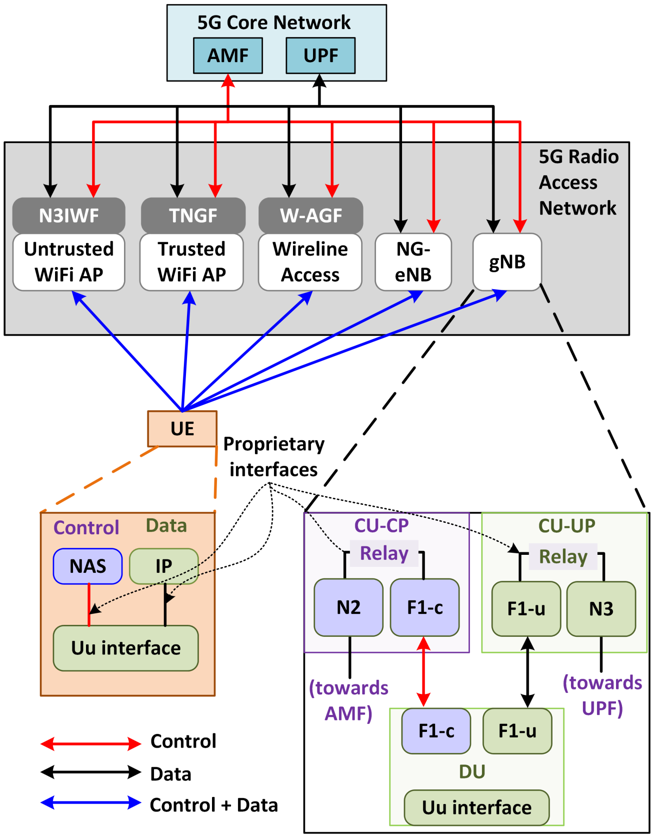

Fig. 1. RAT specific interworking functions and tight and proprietary coupling between radio and core network (CN) protocol stacks (Courtesy [9]). AMF: access and mobility function, UPF: user plane function, UE: user equipment, NAS: non-access stratum, IP: Internet protocol, CU: centralized unit, DU: distributed unit, CP: control plane, and UP: user plane. N3IWF, TNGF and W-AGF are interworking functions for untrusted WiFi AP, trusted WiFi AP and Wireline access respectively.

D. Tight and proprietary coupling between access and core network

There is tight and proprietary coupling between RAN and CN in the 5GS, i.e., between radio and CN protocol stacks (of gNB and user equipment (UE)) as displayed in Fig. 1, which results in an inflexible architecture. The current 5G non-standalone architecture (NSA) can be viewed as an implication of this restriction, wherein a Fourth Generation (4G) RAN node (eNB) is necessary to support connectivity between 5G gNB and 4G CN.

Moreover, it also leads to RAT-specific inter-working functions in RAN, for example, non-3GPP interworking function (N3IWF) for untrusted wireless local area network (WLAN), trusted non-3GPP gateway function (TNGF) for trusted WLAN, and wireline-access gateway function (W-AGF) for wireline access (as shown in Fig. 1) even though their functionalities are quite similar.

E. Dual (or Multi) connectivity

Dual (Multi) connectivity is an important capability of the existing 4G/5G network, it can help support many use cases efficiently [10]. A dual connected UE is connected to two base stations (BSs)/access points (APs) simultaneously. In the existing 3GPP architecture, there are multiple variants for dual connectivity that are RAT specific, for example, LTE-LTE dual connectivity, LTE-WiFi aggregation, and NR-LTE dual connectivity, making its implementation quite complex. This feature also requires extensive coordination between RAN nodes, e.g., eNBs, gNBs and there is a need to simplify its implementation.

F. Load balancing

The existing scheme for load balancing in RAN is a distributed one. Node level load information (between RAN nodes) is exchanged over X2 and Xn interfaces. This effectively rules out load balancing across 3GPP (5G-NR) and non-3GPP RATs (WiFi) in 5GS as no such interface exists between them. Since core also does not have access to load level information of RAN nodes, no mechanism for load balancing across 3GPP and non-3GPP RATs in the 5GS is available as of now.

In the next sections, we review IEEE 1930.1 standard and IEEE P2061 draft and highlight how they address some of the limitations of the existing 5GS architecture.

III. OVERVIEW OF IEEE 1930.1 ARCHITECTURE

The key concepts introduced by IEEE 1930.1 standard (as shown in Fig. 2) are granular disaggregation in RAN and unification of various RATs [6]. RANs of most RATs perform similar functionality such as encryption/decryption of data and signalling, link adaptation, flow optimization (header compression etc.), and interworking with core. Therefore, IEEE 1930.1 proposes the multi-RAT RAN to be disaggregated along the aforementioned functions.

Next we provide a description of IEEE 1930.1 architecture which comprises of a disaggregated data plane, an SDN middleware, a unified multi-RAT RAN controller along with a management and orchestration function (as shown in Fig. 3):

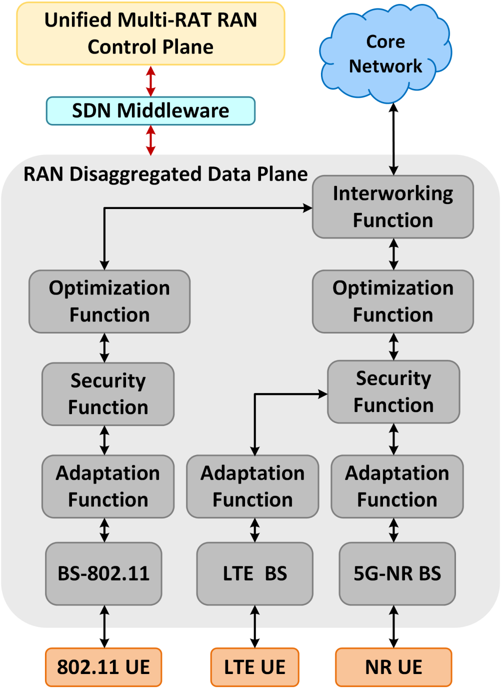

Fig. 2. Block diagram of the proposed architecture in IEEE 1930.1 (Courtesy [6]). UE: user equipement, BS: base station, SDN: software defined network, RAT: radio access technology, RAN: radio access network, LTE: long term evolution, and NR: new radio.

1) Modular data plane functions: RAN disaggregation is achieved via distribution of RAN data plane functionality into granular functions like base station function (BSF), adaptation function (AdpF), security function (SF), optimization function (OptF), and interworking function (IwF). AdpF essentially handles the task of link control/acknowledgments and also supports in-sequence delivery etc. An SF performs encryption and integrity protection, i.e., ensures communications security over wireless medium. OptF performs flow optimization such as IP header compression etc. and/or tasks related to guaranteeing quality of service (QoS) to flows. IwF can be used for inter-working with the core, e.g., to support 3GPP N3 interface towards 5G core. These functions may be RAT specific as well as RAT agnostic. Besides, the RAT-specific BSF includes MAC and lower layer (physical layer) functionalities. For multiple RATs, as shown in Fig. 2, IEEE 802.11 BS, LTE BS, and 5G NR BS are separate access points for these three different RATs. Overall, the data plane functions for various RATs are organized in a more modular fashion.

2) Multi-RAT SDN controller for RAN: A logically centralized and unified SDN controller for multi-RAT RAN is responsible for control and management of RAN data plane functions belonging to different RATs, i.e., it performs control and management of functions such as BSF, AdpF, OptF, SF, or IwF. The controller is aided by the SDN middleware in this task.

3) SDN middleware: SDN middleware is placed in between the (unified multi-RAT) RAN controller and the (multi-RAT) RAN data plane functions. It virtualizes the underlying RAN functions (essentially the access network resources) in terms of a unified abstract information model, which is exported via a northbound interface to the controller. The abstract information model enables the controller to manipulate the network resources in RAN in a unified and RAT agnostic manner.

4) Management and orchestration function: The Management and Orchestration function (or Orchestrator) is also a control plane function that interacts with the network infrastructure (resources or data plane) and manifests an abstract information model (of the network resources) through the SDN middleware.

Some of the key advantages of IEEE 1930.1 architecture are as follows:

i) Scalable RAN: Disaggregation of RAN data plane along with the unification of RATs brings scalability to RAN and bestows it the capability to handle higher data volume and efficient resource utilization.

ii) Multi-RAT load balancing: The unification of RATs along with the disaggregation of RAN in IEEE 1930.1 enables implementation of load balancing between different RATs which may not be feasible today. The multi-RAT SDN controller has a unified view of the resources in RAN and can do load distribution across granular functions and RATs.

iii) Ease and flexibility of dual connectivity implementation: Utilizing IEEE 1930.1 architecture, all possible variants of dual connectivity, e.g., LTE-LTE, NR-NR, NR-LTE, NR-WiFi, LTE-WiFi can be supported uniformly and in a simple manner including variants which may not be supported today (e.g. NR-WiFi). For NR-WiFi dual connected UEs, the multi-RAT RAN controller can establish the data path via common IwF, OptF, SF and RAT specific AdpFs (e.g., one AdpF for IEEE 802.11 AP, the other one for 5G-NR BS), and also RAT specific BSs (IEEE 802.11 AP and 5G-NR BS). Selection of common and RAT specific functions in the data path is flexibly done by the multi-RAT controller making the implementation of dual connectivity in the proposed architecture much simpler and flexible as compared to that of the existing 5GS.

iv) Network slicing support: In IEEE 1930.1 RAN architecture, network slicing can be supported at two levels. At first level, the data plane functions, such as BS, SF, IwF themselves may be distributed across different logical networks (or slices). At other level, the virtual entities manifested by the SDN middleware (over the data plane) may be distributed across different logical networks (network slices) while the underlying data plane functions concurrently support more than one slices. Each of these slices may also have a separate slice specific controller to control them as shown in Fig. 3. Different slices can be created on the basis of different service requirements.

To summarize, IEEE 1930.1 architecture enables a scalable and disaggregated access network through modular and reusable data plane functions. It also allows virtualization of data plane through SDN middleware, and provides unification of various RATs at the RAN level leading to improved load distribution across RATs. Besides, the proposed architecture enables a simpler implementation of features like dual connectivity and network slicing. Although RAN level RAT unification is achieved in IEEE 1930.1, path selection control at UE is still with the CN, which does not allow bypassing the core for any service/data flow. However, this limitation has been overcome in IEEE P2061 architecture (detailed in the next section).

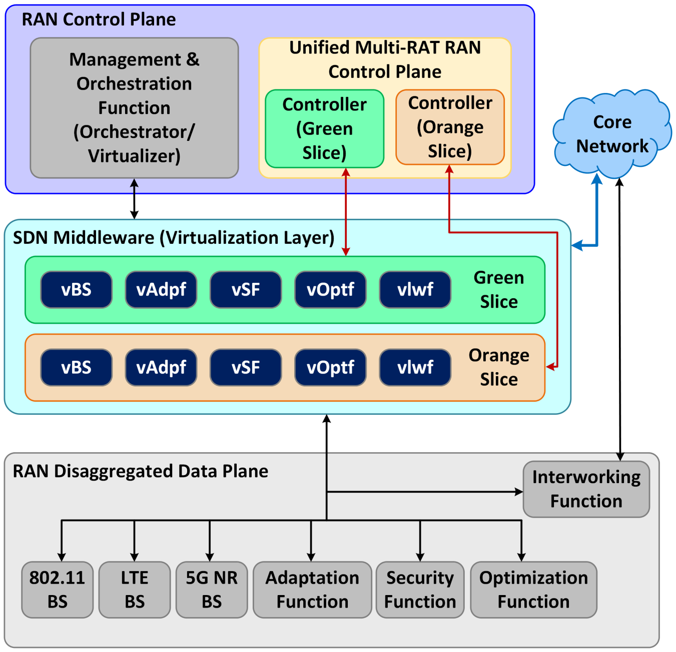

Fig. 3. Multi-RAT unification/virtualization in IEEE 1930.1 RAN architecture (Courtesy [6] having slicing support for two slices (orange and green) with two separate slice controllers and two logical networks (Courtesy [6]). Different slices support different services. For example, the green slice can support Ultra Reliable Low Latency Communications (URLLC) service and the orange slice can support enhanced Mobile Broadband (eMBB) service. SDN: software defined network, RAN: radio access network, LTE: long term evolution, NR: new radio, vAdpF: virtualized adaptation function, vSF: virtualized security function, vOptF: virtualized optimization function, and vIwF: virtualized interworking function.

IV. OVERVIEW OF IEEE P2061 ARCHITECTURE

The architecture as proposed in the upcoming standard IEEE P2061 is named ”Frugal 5G Network”. It refers to the vision of providing affordable broadband access to rural areas by addressing the requirements specific to these areas. Although design goals of the ”Frugal 5G network” are oriented towards rural requirements, some concepts developed as part of the proposed architecture are generic and futuristic and can be used towards building a scalable and flexible mobile network architecture for future.

A typical characteristic of rural areas is that there are relatively (relative to towns/cities) smaller clusters of human habitats surrounded by open and unpopulated or very sparsely populated areas. Considering this, IEEE P2061 proposes a heterogeneous wireless network architecture (shown in Fig. 4) to provide connectivity to rural areas [5], [7]. The architecture consists of one or more small cells to provide high speed connectivity within villages. The small cells in Fig. 4 may be WiFi APs running in infrastructure mode [11]. These WiFi APs (small cells) can be back-hauled using a (preferably wireless) middle mile network (MMN) to a nearby fiber (or fixed-line) point of presence (PoP). The fiber PoP enables connectivity to the Internet, other data networks and also the

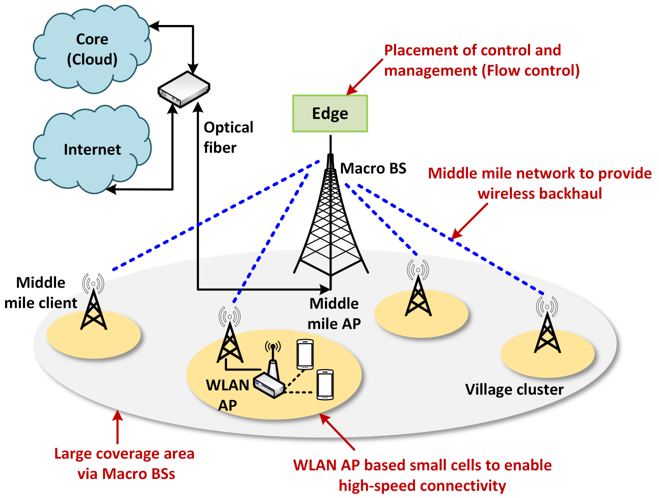

Fig. 4. Conceptual view of IEEE P2061 (Frugal 5G) architecture [5], [7]. WLAN: wireless local area network, BS: base station, and AP: access point.

CN. The small cells in villages are supplemented with macro cells to provide umbrella coverage around the villages to avoid coverage holes. The BS for the macro cell is employed in the vicinity of the PoP and utilizes the fiber link to connect to the CN and the Internet. There is also an edge cloud at the PoP and both the macro cells as well as the small cells (via the MMN) are directly connected to the edge cloud also.

Here we discuss some of the key strengths of IEEE P2061, especially those which may have a bearing on the future mobile network architecture.

1) Unification of RATs: IEEE P2061 also defines a unified multi-RAT RAN architecture utilizing SDN principles. It possesses a hierarchical control structure with separate RAT specific and RAT agnostic control layers. It proposes to replace the existing RAN nodes such as gNBs, eNBs and N3IWFs by a set of SDN switches controlled by an SDN controller. The SDN controller is a RAT agnostic controller. These SDN switches may comprise one or more radio protocol interfaces, e.g., gNB NR radio interface, 4G radio interface, Non-3GPP radio interface, one or more CN interfaces, e.g., 5G-N3, 5G-N2, 4G-S1-MME, and 4G-S1-u interfaces, and possibly a direct interface to the data networks/Internet. RAT specific control functionality may be encapsulated within the interfaces itself on the SDN switches. These may exist along with the data forwarding functionality. For example, gNB NR-Uu interface on the SDN switch may have radio resource control (RRC) layer for NR access control functionality and lower layers such as MAC layer for data forwarding. Similar to AN, an SDN switch is instantiated on UE also, which separates AN interface (e.g. 5G NR interface with RRC and lower layers) on the UE from its higher layers, i.e., CN connectivity layers (non-access stratum (NAS) and tunneling/IP layers). Both UE and AN SDN switches are controlled by the same SDN controller, as shown in Fig. 5. Protocols similar to Open flow (a specification for SDN-based switch [12]) can be employed to control these UE and AN SDN switches. The controller can flexibly direct the UE specific flows (both signalling and data) through appropriate interfaces on the UE and the AN SDN switches.

One key reason behind the absence of a unified RAN and the existence of independent RAT specific entities (in existing RAN) is proprietary and tight coupling between the radio interface protocol stack and the core network interface protocol stacks on RAN entities/nodes. By instantiating these interface stacks as different interfaces (ports) on an SDN switch, the proposed architecture is able to decouple these interfaces from each other and also unify different RATs under the control of a single RAT agnostic SDN controller.

2) Decoupling of RAN from the Core: IEEE P2061 supports decoupling of RAN from CN. Decoupling of AN-CN interfaces with the help of SDN switches allows for the replacement of the existing RAN entities such as a gNB with an SDN switch. It also enables any core to inter-work with any RAN, e.g., 4G Core - 5G RAN, or 6G Core - 5G RAN etc. By treating the UE-CN communication as an overlay communication on the UE-AN link, it brings immense flexibility to the UE-CN communication.

3) Bypassing the core and utilizing intelligence at the edge: The employment of CN to handle user services increases the load on the CN in the existing mobile networks. Such a centralized architecture can be a concern in view of the scalability requirements to handle future traffic demands. The usage of SDN controller and SDN switches in AN along with the decoupling of RAN from CN enables direct connectivity to the external data networks/Internet bypassing the core. This feature also facilitates localized communication within RAN and allows exploitation of edge computing resources efficiently.

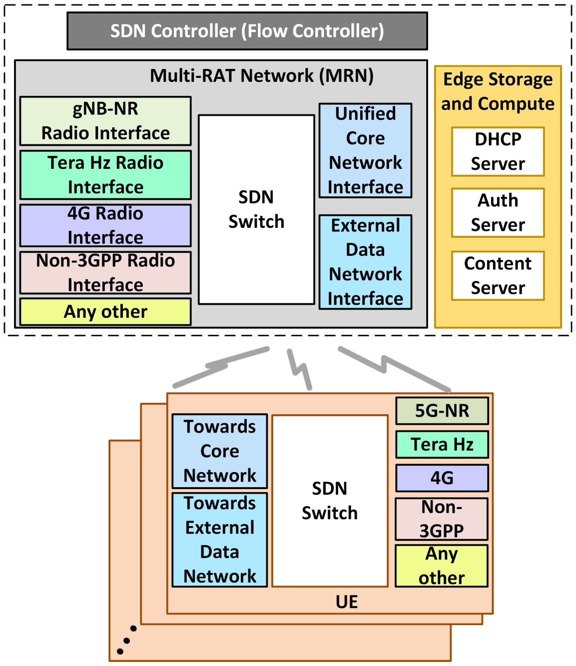

Fig. 5. Implementation of IEEE P2061 RAN in the context of 6G RAN requirements [7]. gNB: gNodeB, NR: new radio, SDN: software defined network, DHCP: dynamic host configuration protocol, and UE: user equipment.

4) Direct connectivity to Internet: The architecture as proposed in IEEE P2061 makes it possible to connect an UE directly to the Internet without involving the CN. The RAN

SDN controller can flexibly set up data paths through the RAN SDN switch to enable direct connectivity to the Internet without involving the core. It allows usage of cellular RAN in an autonomous and standalone manner. In contrast, the RAN in existing 3GPP cellular systems (4G/5G) necessarily requires the CN's support and can not work in a standalone manner.

Even though both IEEE 1930.1 and IEEE P2061 strive to achieve a unified multi-RAT RAN, there are some important differences between the two. The unified multi-RAT RAN, as proposed in standard IEEE 1930.1, works in conjunction with the CN and under overall supervision and control of the CN. IEEE P2061 proposes a multi-RAT RAN that is decoupled from the CN and can function autonomously, which is not possible in IEEE 1930.1. Further, IEEE 1930.1 defines a disaggregated data plane and IEEE P2061 proposes disaggregation for control plane with separate RAT specific and RAT agnostic control layers. Additionally, IEEE 1930.1 proposes an SDN based architecture for RAN but it does not include UEs in the ambit of the SDN based architecture, whereas IEEE P2061 extends the concept of SDN to UEs as well by instantiating an SDN switch on the UE and bringing it (UE's SDN switch) under the control of the RAT agnostic controller (SDN controller). This allows for decoupling of RAN from CN.

In summary, IEEE P2061 enables a flexible mobile network architecture in which any RAN can be used with any core. We can also involve the core selectively only for the purposes of mobility and authentication. As a result, CN's user plane functions and data tunnels are made optional, so it is possible not to use them based on service/flow/user requirements. IEEE P2061 also supports other use cases like captive networks and non-standalone deployment of 3GPP 5GS.

V. AN OUTLINE OF THE 6G AN ARCHITECTURE

Firstly, we identify key design principles for the next generation mobile communications system (6G). We also present an outline of the 6G AN architecture aligned to these principles.

A. Design principles for the 6G system

Meeting the following requirements and guidelines will help us design a scalable and flexible system for the future and also address some of the limitations of the 5GS:

1) Unified multi-access RAN: It should support a unified multi-access RAN enabling a unified treatment for features like dual connectivity, load balancing etc. within and across RATs. There should be a logically centralized control entity in the RAN with a global view of the access network resources. This should lead to a unified multi-RAT RAN control with potential for optimal resource utilization across RATs.

2) Dis-aggregated RAN: It should support further disaggregation of RAN leading to enhanced modularity, scalability and resource utilization. Most RATs perform similar functionality in RAN e.g., medium access, communications security, flow optimization, inter-working with core. Disaggregating RAN along these granular functions may allow it to harness commonality between RATs and facilitate RAT-unification.

3) Differentiated treatment to services: Mobile network should allow differentiated treatment to different use cases. A mechanism in this regard is to have greater flexibility in the usage of core, allowing a data-flow to even bypass it, if needed.

4) Decoupling of RAN from the core: In order to bring flexibility and support differentiated handling of use cases, RAN should be decoupled from the core. Any RAN should be able to connect to any core, such as 5G-RAN should be able to connect to 6G core and 6G-RAN should be able to connect to 5G core, if needed.

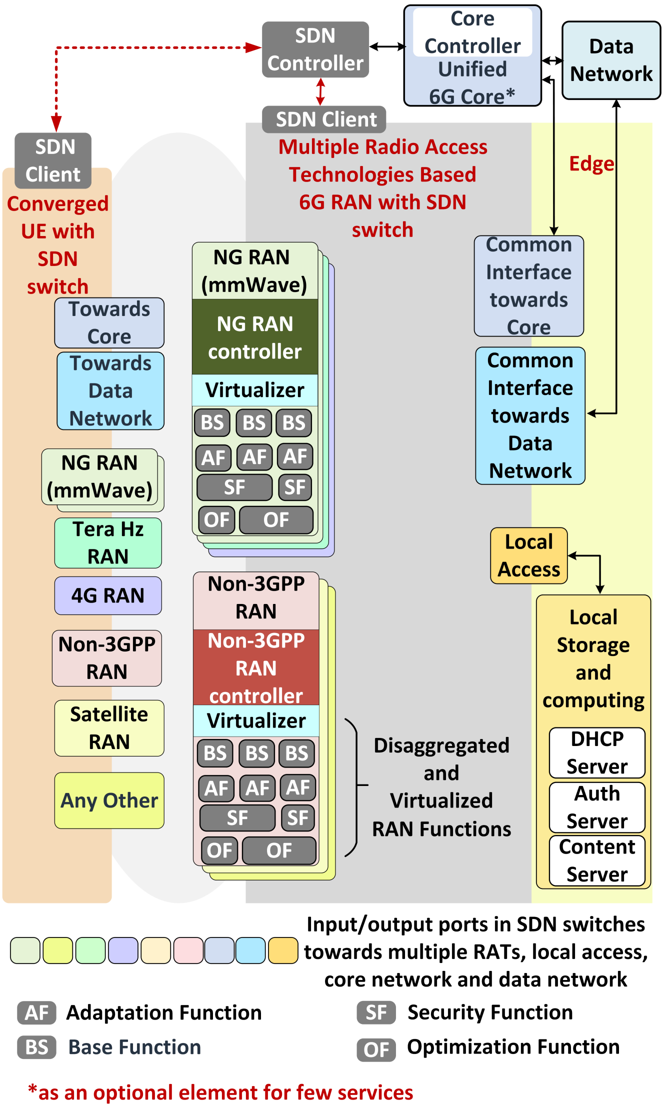

Fig. 6. Conceptual framework for 6G architecture based on the learnings from IEEE 1930.1 and IEEE P2061.

B. 6G AN architecture - a conceptual framework

Considering the above requirements, we present a conceptual framework for 6G RAN architecture (Fig. 6). Incorporating design ideas from IEEE 1930.1 and IEEE P2061, we propose extensive utilization of SDN technology in AN. The RAT specific RAN entities such as gNB, eNB, N3IWF of the existing 3GPP 5G system can be replaced with SDN switches and SDN controllers. The SDN switches may have multiple ports or interfaces. Both, the SDN switches and the interfaces therein, may be logical entities and not necessarily physical entities. The interfaces on the RAN SDN switches may be used to provide radio connectivity to UEs or to provide connectivity to the CN or to the external data networks. A single interface supporting radio connectivity to UEs may support one or more RATs. The architecture may have a hierarchical control structure with a RAT agnostic controller responsible for overall control of the RAN. Further, the individual interfaces within a RAN SDN switch can have a separate controller with underlying disaggregated and virtualized RAN functions, e.g., BSF, AdpF, SF, OptF etc. If a single interface incorporates multiple RATs then the encapsulated controller (within the interface) would be a multi-RAT controller in line with the ideas proposed in IEEE 1930.1.

In addition, a UE can also incorporate an SDN switch, including logical ports and physical interfaces towards one or more ANs similar to what has been proposed in IEEE P2061. The SDN controller can control the data flow through the network by updating the flow tables in SDN switches of RAN and the UEs. There may be local storage and computing module at the edge which can provide localized services without involving the core. Besides, UEs can directly connect to the data network via RAN bypassing the core, if desirable. As highlighted earlier, such a mechanism may have benefits in certain scenarios. The architecture can also support decoupling of RAN from the core allowing inter-working of different generations/types of ANs and CNs, e.g., inter-working of 5G RAN & 6G core or 6G RAN & 5G core, or WiFi access & 6G core.

VI. CONCLUSION

Future mobile networks are expected to transport huge volume of data and handle an immense diversity of use cases. In order to support these requirements, beyond 5G networks would need certain architectural enhancements. In this regard, IEEE 1930.1 and P2061 may play important roles. As the design principles introduced in these standards enable a flexible and scalable architecture for mobile networks; these standards may help set the direction for the evolution of mobile network architecture in beyond 5G era. In this context, we have highlighted some of the limitations of the 3GPP 5GS architecture such as uniform treatment to all use cases and tight coupling between AN and CN. Additionally, we have elaborated on the key design concepts introduced by IEEE 1930.1 and P2061. We have also proposed a conceptual framework for the 6G architecture utilizing these design concepts. The proposed architecture includes a disaggregated, granular and unified multi-RAT RAN with support for virtualization. It allows for ease of implementation, easy incorporation of new RATs, direct connectivity to the Internet from RAN, efficient edge computing, localized communication, and differentiated handling of services. Further, it can also pave the way to an energy-efficient and intelligent 6G network.

ACKNOWLEDGMENTS

We acknowledge working group members for their contributions towards standards IEEE 1930.1 and IEEE P2061 draft. We also acknowledge the Ministry of Electronics and Information Technology (MeitY), Government of India for their support.

REFERENCES

[1] Ericsson, "Ericsson Mobility Report," *Report*, June, 2022. [Online]. Available: https://www.ericsson.com/en/reports-and-papers/mobility-report/reports/june-2022

[2] "National Digital Communication Policy," 2018. [Online]. Available: https://dot.gov.in/sites/default/files/EnglishPolicy-NDCP.pdf

[3] TRAI, "Highlights of Telecom Subscription Data as on 30th September, 2021," *Report*, 2021. [Online]. Available: https://www.trai.gov.in/sites/default/files/PR_No.50of2021_0.pdf

[4] Sue Rudd, "5G Signaling and Control Plane Traffic Depends on Service Communications Proxy (SCP)," *Strategy Analytics Report*, 15 December 2021. [Online]. Available: https://carrier.huawei.com/~/media/cnbgv2/download/products/core/strategy-analytics-5g-signaling-en.pdf

[5] M. Khaturia, P. Jha, and A. Karandikar, "Connecting the Unconnected: Toward Frugal 5G Network Architecture and Standardization," *IEEE Communications Standards Magazine*, vol. 4, no. 2, pp. 64–71, 2020.

[6] IEEE Std 1930.1, "Recommended Practice for Software Defined Networking (SDN) based Middleware for Control and Management of Wireless Networks," *Technical Standard*, 2022. [Online]. Available: https://standards.ieee.org/ieee/1930.1/10917/

[7] IEEE P2061, "Architecture for Low Mobility Energy Efficient Network for Affordable Broadband Access," *Ongoing Technical Standard*, Active PAR 2022. [Online]. Available: https://standards.ieee.org/ieee/2061/7313/

[8] 3GPP, "5G; NG-RAN; Architecture description (3GPP TS 38.401 version 15.5.0 Release 15) ," *Technical Standard*, 2019.

[9] M. Khaturia, P. Jha, and A. Karandikar, "5G-Flow: A unified Multi-RAT RAN architecture for beyond 5G networks," *Computer Networks*, vol. 198, p. 108412, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1389128621003820

[10] A. Nayak Manjeshwar, P. Jha, A. Karandikar, and P. Chaporkar, "Enhanced UE slice availability and mobility through multi-connectivity in 5G multi-RAT networks," *Internet Technology Letters, Special Issue on MOBISLICE-SI-2019*, vol. 3, no. 6, p. e184, 2020. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/itl2.184

[11] IEEE Std 802.11, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," *Technical Standard*, 2020. [Online]. Available: https://standards.ieee.org/ieee/802.11/7028/

[12] Open Networking Foundation, "OpenFlow Switch Specification Version 1.3.0 (Wire Protocol 0x04)," *OpenFlow Spec*, 2012.