Virtual RATs and a Flexible and Tailored Radio Access Network Evolving to 5G

The authors describe a new method for radio access technologies called virtual RATs. The proposed scheme can provide a flexible and tailored access network that can meet the requirements and overcome the challenges in mobile broadband networks. They also present a high level design of the overall architecture and protocol stack for virtual RATs.

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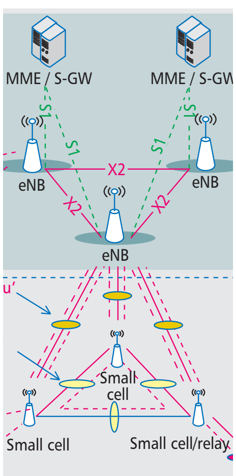

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Abstract

This article first analyzes the requirements and challenges in the future 5G mobile wireless network. Then the authors describe a new method for radio access technologies called virtual RATs. The proposed scheme can provide a flexible and tailored access network that can meet the requirements and overcome the challenges in mobile broadband networks. The authors also present a high level design of the overall architecture and protocol stack for virtual RATs. Two concepts, virtual RAT Types and interface sets, are introduced. Two essential features, flexible control/user (C/U) plane separation and coordination between virtual RATs, are also discussed. Examples are provided to show how to achieve a flexible and tailored access network for services by using virtual RATs. Finally, the capability of hardware to support implementation of virtual RATs is analyzed.

Introduction

Nowadays, the dramatic growth of mobile data services, driven by the wireless Internet, the Internet of Things (IoT), mobile cloud, and smart devices, is presenting more challenges to radio access network design for the fifth generation (5G) mobile communication systems. Different people may have different views about the future radio access network. However, one common idea has been widely accepted, i.e., that multiple RATs will simultaneously exist in 5G [1], meaning there will be more new RATs to be developed in order to satisfy the increasing requirements of different user cases. For example, one new RAT might be developed to support the high data rate of 10 Gbps or above, while another new RAT might be designed to support machine to machine (M2M) services with a large number of users and low data rate. Subsequently, the issue arises of how to efficiently design those different RATs, and how to define and deal with various RATs will be an inportant factor when designing the architecture of the future access network. In this article we categorize three evolving phases for various RATs according to the level of inter-working efficiency in a heterogonous radio network: stand-alone RATs, integrated RATs, and virtual RATs. Then, the high level design of virtual RATs is investigated to provide a flexible and tailored network in the future.

The remainder of this article is organized as follows. We analyze future requirements and challenges and indicate that virtual RATs will be needed to meet those requirements and overcome those challenges. We present a virtual RATs design at a high level of the overall architecture and protocol stack by introducing two concepts: virtual RATs types and interface sets. Two other essential features, flexible C/U plane separation and coordination between virtual RATs, are also discussed. Examples are provided to show how to achieve flexible and tailored access networks for services by using virtual RATs. We then analyze the capability of hardware to support implementation of virtual RATs.

Future Challenges and the Concept of Virtual RATs

There will be many more new services and applications in future networks. New applications such as the Internet of Things, social networks, mobile cloud, and public safety will be efficiently provided by radio access networks. Those new applications have different requirements than those of traditional mobile services. For example, the number of subscribers for IoT will increase 100 to 500 times while power consumption will decrease several ten times than that of normal mobile devices. Social network applications may request direct communications between terminals instead of communicating through a core network. Mobile cloud services will depend on huge amounts of information being exchanged between core networks and terminals with very low transport latency. Public safety will require the ability to communicate in emergency situations, especially in natural disasters such as earthquakes, when the public mobile communication systems are down. A method of multiple radio access technologies (multi-RATs) is a possible way to support multiple services. Actually, multi-RATs such as 3G/4G and WiFi have already been used to provide voice and data services in the current network under different scenarios. However, there are still new challenges presented by multi-RATs design. First, many rich and diverse services need to be supported by as few RATS as possible, to minimize the cost and complexity of devices. Second, seamless handover and dynamic offloading between different RATs needs to be supported to provide a high quality of experience (QoE) for users. Third, sharing and optimization of radio access resources between different RATs is needed to achieve higher spectrum efficiency as spectrum resources are becoming scarce and the data rate is increasing. Besides, the installation and cost for multiple networks of multi-RATs need to be significantly reduced. All of those challenges are

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difficult to handle by using traditional inter-working methods of multi-RATs.

The first traditional inter-working method of multi-RATs is through stand-alone RATs. By using this method, different RATs work alone and provide different services. Each RAT keeps its protocol stack, and runs in each software and hardware platform. There is no information exchange between different RATs. The switch between different RATs is performed by manual operation. It is obvious that stand-alone RATs cannot meet the requirements of multi-RATs.

The second traditional inter-working method is integrated RATs, in which different RATs keep their respective architecture and protocol stack running in each software and hardware platform. However, integrated RATs can have some coordination in the radio access and the core network. The switch between different RATs can be executed automatically. One typical example is the case of 3GPP-WLAN interworking. Several solutions for WLAN offloading based on dual connectivity are defined to offload the traffic between 3GPP and WLANs seamlessly in 3GPP Release 12 [2]. Recently, another work item (WI) for LTE-WLAN Radio Level Integration and Interworking Enhancement was approved in 3GPP Release 13. It allows for real-time channel and load aware radio resource management across WLAN and LTE. 3GPP Release 13 can thus provide significant capacity and QoE improvements [3]. Although the integrated RATs method offers significant improvements over the stand-alone RATs method, it is still not able to deal with the challenges that we discussed above. Integrated RATs does not combine different RATs at the software and hardware levels, and thus cannot achieve the low cost and low complexity of devices, especially when more RATs are needed to provide richer services and applications. The interworking in the Packet Data Convergence Protocol (PDCP) has limitations to achieve higher spectrum efficiency.

Therefore, we propose a new multi-RATs method called virtual RATs. In virtual RATs, a common architecture and protocol stack are based on the 3GPP network to achieve a smooth evolution from legacy networks. The architecture and protocol stack for different RATs can be tailored or revised from the common architecture and protocol stack. Virtual RATs can be programmed after that. The information can be exchanged at each level to optimize the utilization of radio resources and to improve spectrum efficiency. Different RATs may work in a common software and hardware platform. However, there are differences between virtual RATs and the open source software method. By introducing the concepts of interface sets and virtual RAT types, virtual RATs can gain more advantages in security and interworking than the open source software method. Comparisons are shown in Table 1.

	Stand-alone RATs	Integrated RATs	Virtual RATs
Architecture and protocol stack	Different	Different	Common, flexible, and tailored
Hardware platform	Independent	Different	Common
Coordination and interworking between different RATs	No	Automatically, in the core network	Automatically, in the core network, L2 layer, and physical layer
Information exchange	No	Limited	Optimize
Cost	High	Medium	Low
Complexity	Low	High	Medium
QoE	Low	Medium	High

Table 1. Comparisons among stand-alone RATs, integrated RATs, and virtual RATs.

Virtual RATs Design for Future Radio Access Networks

In this section we present the high level design of Virtual RATs, including the overall architecture design by introducing a concept of interface sets, and the protocol stack design by introducing virtual RAT types. Meanwhile, the differences between the virtual RATs design and the open source software RAT design are also pointed out. In addition, we discuss two other important topics: flexible C/U plane separations and the coordination between RAT types, which are closely related to the virtual RATs design.

A Flexible and Tailored Overall Architecture Design by using Interface Sets

In general, an overall architecture design at the high level for a mobile system mainly consists of the definition of network components and the definition of interfaces between the network components.

Different kinds of low power nodes such as small cell, relay, and device-to-device (D2D) will appear beside traditional macro cell and micro cell [4]. Although those components of low power nodes have been heavily discussed in 3GPP, they are not explicitly included in the current overall architecture that is shown in Part 1 in Fig. 1 [5]. The reason is that the legacy mobile system such as the second generation (2G), 3G, and even the early version of 4G are mainly focussed on macro-coverage based design [6]. In other words, the air interface technologies have always been kept the same in order to keep the compatibility for both the macro-coverage scenario and the indoor/hotspot coverage scenario. So we called Part 1 the architecture for the macro-based International Mobile Telecommunications (IMT) path. It is obvious that the architecture in Part 1 is not ribust enough to be the architecture for future radio access networks. As analyzed in [7], low power nodes will play a very important role in the future network to meet the new requirements in traffic volume, frequency efficiency, energy, cost, and so on. Since there are significant differences between the indoor/hotspot scenario and the macro scenario, it is reasonable that an additional part of the architecture, for low power nodes used in

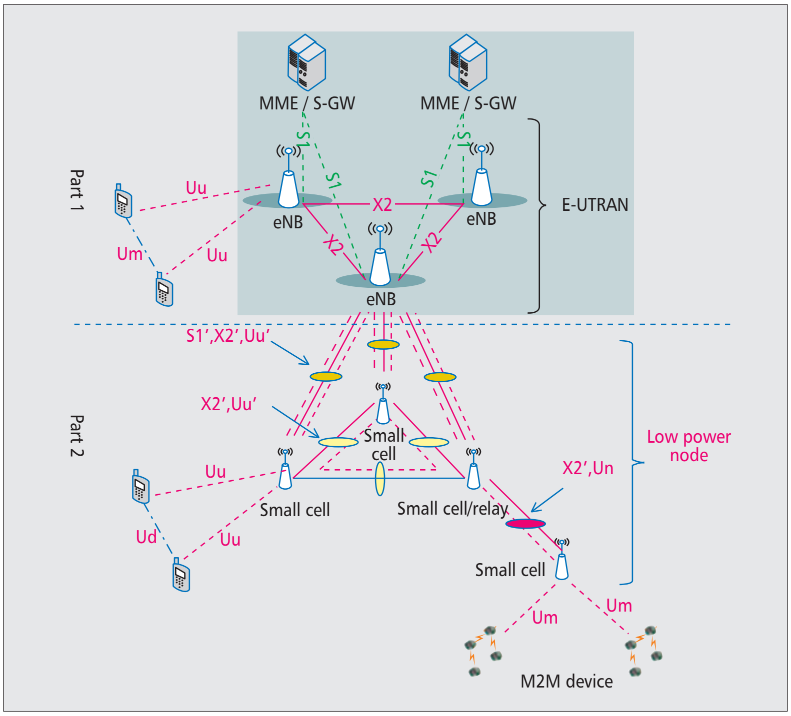

Figure 1. Overall architecture for of future radio access network.

indoor/ hotspot scenario, needs to be introduced in the overall architecture for future radio access networks. This additional part of the architecture we proposed for low power nodes is shown as Part 2 in Fig. 1.

The introduction of the architecture for low power nodes may raise another issue, i.e., how to define the interfaces between low power nodes as well as between low power nodes and macro cell base stations. The interface definitions always have difficulties in practice since several key requirements should be taken into account together including flexibility, programming, inter-working, security, system performance, and the cost to upgrade from legacy architectures.

To deal with those difficulties, we put forward the concept of "interface sets" in future radio access networks (especially for 5G). "Interface sets" is a set of interfaces that might be used in two peered entities. Each interface in the set can be programmed for one scenario and the interfaces can be selected and downloaded to run correspondingly to the actual scenario. Each interface in the set needs to be validated by a third party to provide inter-working between node and node, node and terminal. The interface is designed based on existing interfaces. We define three interface sets in Fig. 1: an interface set of "S1', X2', Uu'" is between an E-UTRAN Node B (eNB) and a small cell; an interface set of "X2', Uu'" is between a small cell and a small cell; and an interface set of "X2', Un'" is between a small cell and a relay. By introducing "interface sets," an optimized balance can be achieved to improve the flexibility, programmable, security, system performance, and updating cost. Since an interface can be selected according to an actual scenario and a new interface can be added by programming according to a new scenario, a fairly high degree of flexibility is achieved. For example, an interface set "S1', X2', Uu'" between an eNB and a small cell can support different kinds of backhaul methods for a small cell. S1' can be selected when wired backhaul is used. Uu' can be selected when wireless backhaul is used. X2' is used while requiring a direct backhaul between a small cell and a core network. More important, security can be guaranteed because the programming of the interface set can only be done by operators. Validation of the programming of interface sets may be needed to maintain inter-working between the nodes and devices from different manufactures. In addition, S1', X2', Uu' are defined respectively by revising them from the existing interfaces of S1, X2 and Uu, so the impact to the current architecture can be minimized.

A Flexible Protocol Stack Design for Radio Access Network by Using Virtual RAT Types

As we have discussed before, having one RAT provide one kind of service is not feasible when many more kinds of services need to be supported in future radio access networks. The best scheme is to support multiple kinds of services by using one common protocol stack, with information exchanged easily between each peered layer to achieve high QoE and efficiency.

Thus, we introduce the concept of virtual RAT types to achieve this goal. As shown in Fig. 2, one common protocol stack based on the 3GPP network is used which consists of the physical layer (PHY), the media control layer (MAC), radio link control (RLC), and radio resource control (RRC). The protocol stack for one RAT is revised from the common protocol stack and is programmed to one software package. The created software packages, for different RATs to support different kinds of services, run in the same hardware platform. Thus, the cost and integration complexity of devices can be reduced by using one hardware platform; and owing to software-based programming, the information exchange between peered layers can be easily achieved to support seamless handover and dynamic offloading between different RATs. In addition, the radio resource for all RATs can be managed by single self organizing networks (SON). So the optimization of radio access resources between different RATs is also available to improve spectrum efficiency.

Although virtual RAT types are software-defined, they are different from common open programming. First, virtual RAT types are revised from one common protocol stack based on the 3GPP network. Second, the air interface corresponding to one virtual RAT type is always selected from the interface sets we discussed above. So the virtual RAT types also receive the benefits of inter-working and security just as in the interface sets.

In Fig. 2 we illustrate an example of implementing two virtual RAT types in the same hardware with a single SON controller. The differences between virtual RATs and standalone RATs and integrated RATs are also shown.

Different from Open Source Software Design

Programmable technology seems to be the promising trend for the development of future radio access networks. The designs of interface

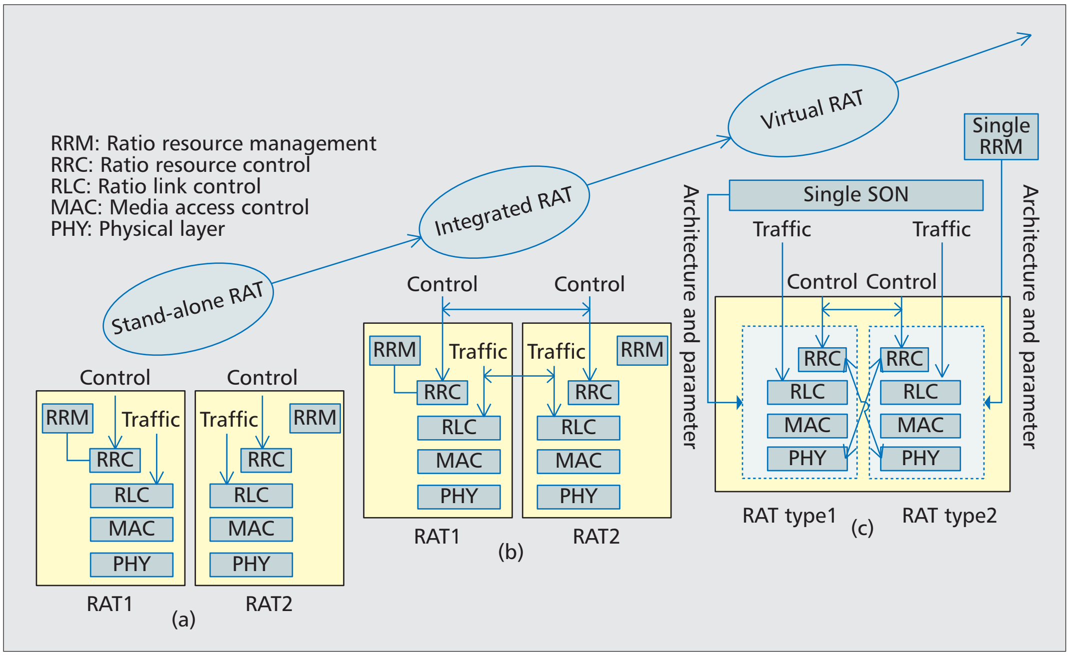

Figure 2. Illustration of three kinds of multi-RATs.

The validation of the design for Interface Set and Virtual RAT Types will provide good inter-working between the eNB and devices from different manufactures. In addition, the design for Interface Set and Virtual RAT Types are based on the re-use of the interface and RAT architecture of the legacy network.

sets and virtual RAT types are both software-based programmable designs, which offers the benefits of flexibility. However, our programmable RAT is different from open source software. Open source software offers freedom to freely use, change, and share the software. Third party developers may develop different radio systems according to different applications through programming on our platform. Open source software may have critical difficulties in security, inter-working, system performance, and updating cost. For example, open source software in radio architectures may facilitate the development of malicious masquerade eNBs and cause trouble for mobile users. Open source software might decrease system performance while optimizing for an individual user. On the other hand, constraints shall be set for the design of programmable interface sets and virtual RAT types, so benefits such as flexibility from programmable methods are achievable while the drawbacks from programmable methods are avoided. For example, the design for interface sets and virtual RAT types shall be manageable by operators or other administration supervisors to guarantee security. The validation of the design for interface sets and virtual RAT types will provide good inter-working between the eNB and devices from different manufactures. In addition, the design for interface set and virtual RAT types are based on the re-use of the interface and RAT architecture of the legacy network. Thus, the updating cost will be lower. The design for interface sets and virtual RAT types achieve good balance among programmable method, security, inter-working, system performance, and updating cost.

Flexible C/U Plane Separations and Combinations

Flexible C/U plane separations and combinations is an important feature in future networks, and has a very close relationship with virtual RATs. Flexible C/U plane separations and combinations are necessary in order for virtual RATs design to accomplish the real flexible C/U plane separations and combinations. In current radio networks, the C plane and the U plane can be separated only between one terminal and one eNB, as shown in the cases of user equipment (UE) 1 and UE 4 in Fig. 3. This method is suitable for basic mobile services such as voice, moderate data services, and machine to machine (M2M) services. In order to support more complicated cases such as high mobility and high data rate mobile services in heterogeneous network, more flexible C/U separations and combinations need to be introduced. For example, as shown the case of UE 2 in Fig. 3, the C plane is connected with a macro eNB while the U plane is connected with a small cell. The advantage is that the high data rate can be offloaded to the small cell while the good mobility is kept by the C plane connection to the macro cell. The related research work on this kind of separation has been ongoing in 3GPP. Furthermore, a wide separation can be supported for cases between one terminal and multiple stations crossing different RATs, as shown in the case of UE 3 in Fig. 3. Thus, capacity is provided by one RAT and mobility is provided by another RAT for one terminal. With this approach, flexible separations and combinations of the C/U plane will be supported, and different kinds of C/U planes can be selected according to the service case and the terminal's ability.

Coordination between Virtual RATs

Coordination between the different RATs is very useful to provide a high QoE and good user experience as well as to improve spectrum efficiency by optimizing utilization of radio access resources.

There are rich coordination paths for virtual RATs, including in the core network, the data link layer (L2 layer), and the physical layer. Furthermore, coordination in radio resource management (RRM) is also feasible by using a

Virtual RATs can achieve carry aggregation, interference coordination, and mitigation between different RATs. System performance can be significantly improved, and a new scheme for RF coordination named Centralized, Cooperative, Cloud and C-RAN is under investigation in the Next Generation Mobile Network.

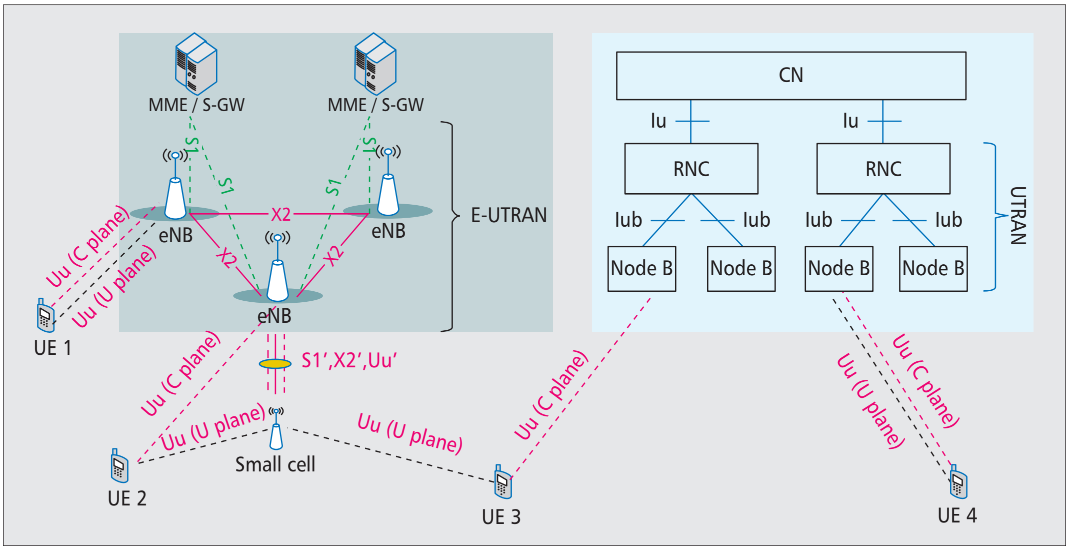

Figure 3. Examples of C/U flexible separations and combinations.

converged SON for different virtual RATs. Before Release 12, 3GPP mainly focused on the standardization in the core network limited by the integrated method of multi-RATs [8–10]. Owing to coordination in the L2 layer, virtual RATs can maximize radio resource efficiency and minimize interference and delay. Owing to coordination in the physical layer, virtual RATs can achieve carry aggregation, interference coordination, and mitigation between different RATs. System performance can be significantly improved, and a new scheme for RF coordination named centralized, cooperative, cloud and clean RAN (C-RAN) is under investigation in the Next Generation Mobile Network (NGMN) [11].

Examples of Using Virtual RATs

We can achieve the high level design of the overall architecture and protocol stack for virtual RATs to support typical new services in the future in a flexible and tailored way. Some examples are given as followed.

Figure 4a presents an overall architecture and protocol stack for D2D services. In this case, two different RAT types are tailored. One is the D2D data virtual RAT type transmitting the D2D data between the two UEs. Another is the normal cellular virtual RAT type providing the cellular traffic. The D2D virtual RAT type can be tailored to be the same with the U plane of the Uu interface of cellular virtual RAT type below the RLC layer so that the software and hardware resources in both the terminal and the eNB can be shared.

Figure 4b gives an illustration of the overall architecture and the protocol architecture for a group call to be used when the public cellular network has been damaged in a disaster. An emergency virtual RAT type can be tailored to terminals to accomplish direct communications between terminals nearby by removing PDCP, and simplifying RRC, as well as adding group call control (GCC) with gateway functionalities. For temporary eNBs, both the emergency virtual RAT type and the normal Virtual RAT type will be tailored to provide access between terminals and terminals. A terminal can act as a temporary eNB such as UE 3.

Figure 4c gives an overall architecture and protocol architecture for M2M services. In general, M2M services always have small data packets in a long idling period with low mobility and extremely low power consumption [12]. To meet those requirements of M2M, the architecture and protocol architecture need to be tailored to a large extent to efficiently meet such types of services. M2M access points will bring huge numbers of M2M subscribers to clusters, not directly to eNBs. PDCP and RRC modules can be removed to dramatically save the terminal's power and cost.

Implementation Feasibility in Hardware to Support Virtual RATs

Hardware flexibility for virtual RATs is essential. Most challenges will be in the physical layer, including the RF and baseband. Above the physical layer, the implementation of protocol stacks and interfaces are already based on software and can be adapted to future virtual RATs.

The first challenge in the eNB physical layer is the cost of the RF radio frequency transceiver (TRx). To support multiple RATs in different RF bands, we should design a RF TRx with different bandwidth, dynamic range, sensitivities, and output power levels. For each band, we need many passive RF components for filtering, switching, matching, and connections. By integrating more RATs (more bands), the cost of passive components increases rapidly and dominates the total cost of an eNB. To reduce the cost, we need integration technologies for passive RF components.

The second challenge is the design complexity of the digital base band (DBB) integrated circuit (IC) in an eNB for multiple RATs. Total computing cost is more than 2×10^{11} operations per second for a full band LTE with single antenna in a sector of an eNB. An eNB usually consists of three sectors with four antennas in each sector. The DBB computing cost is thus more than three trillion

[1] https://www.opennetworking.org/

[2] http://www.etsi.org

[3] http://www.etsi.org/technologies-clusters/technologies/nfv

[4] https://www.ietf.org

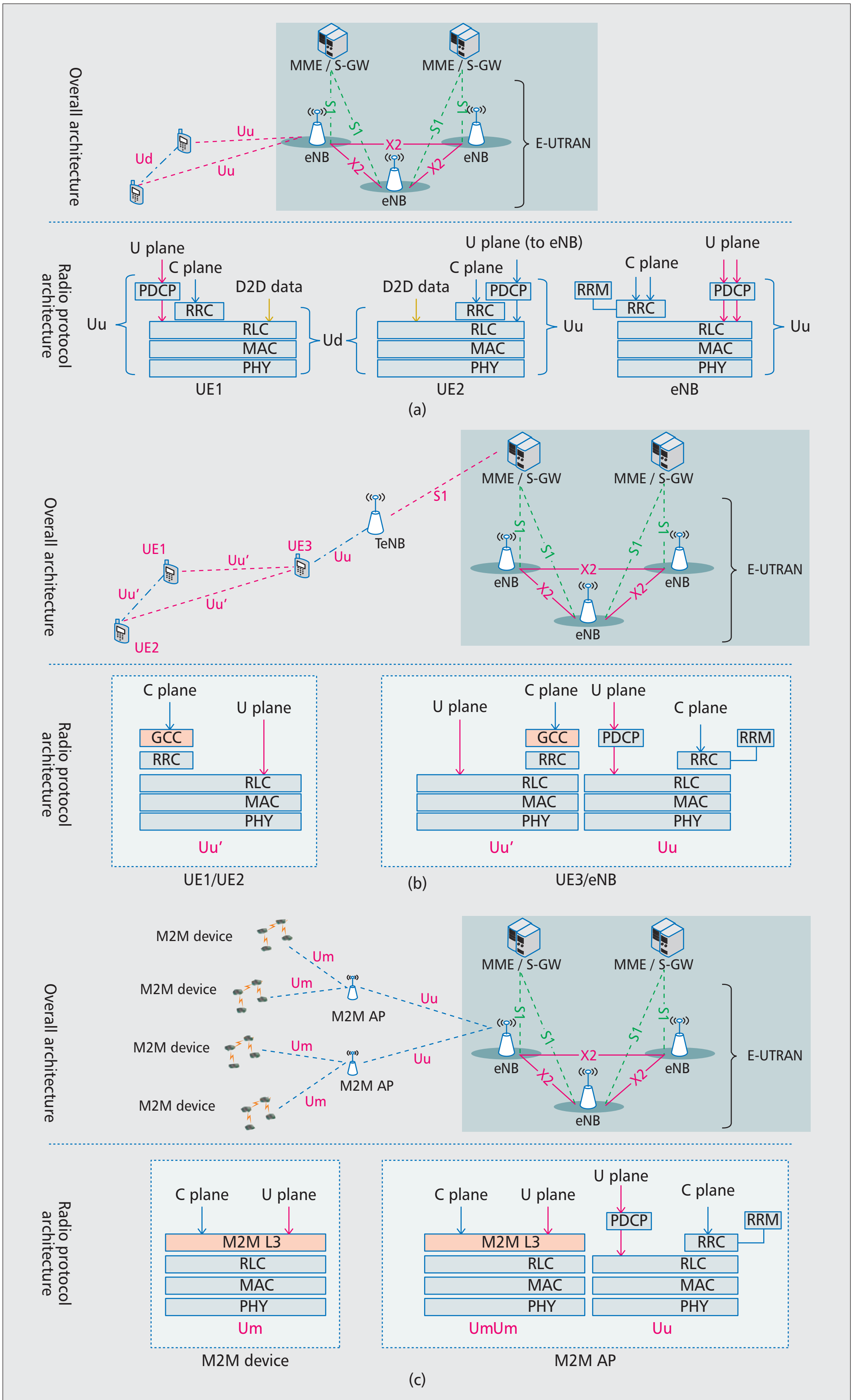

Figure 4. Examples of overall architecture and protocol: a) tailored overall and protocol architecture for D2D; b) tailored overall architecture and protocol for group call; (c) tailored overall architecture and protocol for M2M

Hardware flexibility for Virtual RATs is essential. Most challenges will be in the physical layer, including the RF and baseband. Above the physical layer, the implementation of protocol stacks and interfaces are already based on software and can be adapted to the future Virtual RATs.

Our solution provides a good tradeoff between flexibility, programmability, security, interworking, system performance optimization, and controlloing the cost of network upgrades. Meanwhile, improved hardware technologies will make it possible to implement our solution with reasonable cost and complexity in the future.

operations per second (TOPS). To meet the computing latency constraints, two GPU (GTX-590) modules are needed, each consuming 600 Watts with the cost of $1400. An application specific instruction-set processor (ASIP) for SDR will thus be a necessary technology offering both performance and flexibility with acceptable power [13]. To support baseband for OFDM (LTE and WLAN) and single carrier (GSM and CDMA), we need an efficient, high performance, and low power DBB ASIP. A DBB ASIP consists of three processor clusters: the symbol processor (for transformation, filtering, matrix, and function computing of complex/ real data); the FEC processor (forward error correction of decoding Turbo, LDPC, RS, and Viterbi); and the bit parallel processor (handling low latency bit level parallel processing). Symbol and FEC processors were on the market, there are early bit parallel ASIP prototypes currently available. The cost and power of ASIP DBB for volume products will thus be in the tens dollar range and on the tens Watts level.

The cost of silicon technologies and IC continues to decrease. The cost of passive components also can be decreased by the integration of passive components. It is predictable that the extra cost induced by virtual RATs will be acceptable in the next few years thanks to the use of new technologies and successful hardware sharing and integration.

Conclusions

In summary, new methods of multi-RATs need to be investigated in order to meet the new requirements and challenges of services in the future 5G networks. In this article we have presented a virtual RATs solution to support a flexible and tailored radio access network in the future that would provide high performance at low cost. Two concepts, virtual RATs types and interface sets, were put forward. Instead of building open source software, our solution emphasizes the requirements for security and inter-working. Two important features, flexible C/U plane separation and coordination between RATs, were discussed. Toward 5G, the evolving flexible overall architecture and its radio protocol are based on LTE and LTE-Advanced networks, in order to make a smooth evolution from legacy networks. Our solution provides a good tradeoff between flexibility, programmability, security, inter-working, system performance optimization, and controlloing the cost of network upgrades. Meanwhile, improved hardware technologies will make it possible to implement our solution with reasonable cost and complexity in the future.

Acknowledgment

This work was partly supported by the National Science and Technology Major Project (No. 2013ZX03001025-001) in China, and the National Natural Science Foundation of China for Distinguished Young Scholar under Grant 61425012.

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