A Cybertwin based Network Architecture for 6G

Quan Yu*, Jing Ren†, Haibo Zhou‡, and Wei Zhang⋆
*Peng Cheng Laboratory, Shenzhen, China
†University of Electronic Science and Technology of China, Chengdu, China
‡Nanjing University, Nanjing, China
⋆The University of New South Wales, Sydney, Australia
E-mail: quanyu@ieee.org; renjing@uestc.edu.cn; haibozhou@nju.edu.cn; w.zhang@unsw.edu.au

***Abstract*—In this paper, we first introduce a new network paradigm, called cybertwin based network architecture for 6G, which consists a cloud-centric network architecture and a radio access network architecture. The cybertwin serves as communications assistant, network behavior logger, and digital asset owner. The proposed cloud-centric network architecture can allocate computing, caching, communications resources coordinately, support locator/identifier separation, provide some embed security properties, and support the data market for privacy data. The new radio access network architecture, which can fully decouple the control and data base stations and entirely separate uplink and downlink, significantly enhance the spectrum utilization, reduce the network energy consumption and improve the quality of user experience.**

***Index Terms*—6G, Network Architecture, Internet, RAN, Cybertwin**

I. Introduction

By the end of 2019, dozens of countries have announced that they are rolling out 5G, i.e., the fifth-generation wireless technology for digital cellular networks, which can provide faster speed and lower latency. At the same time, the research community is already looking ahead to beyond-5G solutions and the 2030 era, i.e., 6G [1]–[3].

Although it is not clear what 6G will be like, in line with the previous mobile cellular generation upgrades, the performance indicators for 6G, once again point to an increase by a factor of 10-100 [2]. However, we cannot achieve these performances by merely using higher frequency bands, smaller cell size, more antennas, and more advanced physical and MAC-layer techniques. There is an increasing requirement for upgrading the networking paradigm, which we have already used for 50 years. Some new requirements about network paradigm upgrade are listed as follows:

- **New Network Architecture:** Typically, the evolvement of wireless technology for the digital cellular network is independent of the Internet as they have different design purposes in the beginning. Nowadays, the primary usage of mobile devices is to access online application services instead of making a phone call, as illustrated in Figure 1. It means a mobile device should retrieve data it needs through the Internet. However, the current Internet follows the end-to-end paradigm and only provide "best-effort" delivery. The network performance, such as end-to-end latency, throughput, and transmission rate, cannot meet the design requirements of 6G, even if the data rate is very high at the RAN side.
  On the other hand, 6G should handle the increasing demand of billions of people and hundreds of billions of devices [5]. However, in the current Internet architecture, IP address has two means, i.e., the device's identity and its locator. Once a device moves to another network, both identity and locator will change, which breaks the upper layer's connection and lead to packet loss. Thus, the current Internet cannot work well with the mobile network, and a new network architecture is needed.
- **New Radio Access Network Architecture:** To achieve 10-100 performance improvement, predictably, 6G will employ higher frequency bands and smaller cell sizes. However, using higher frequency bands may suffer from severe path loss, and smaller cell sizes mean more power consumption and operational cost for operators. Thus, we cannot increase the frequency bands and decrease the cell size without limit, which means spectrum resource is always scarce, and some more efficient methods are needed.
  Keeping this problem in mind, we observe that the current spectrum utilization is ineffective. For example, the spectrum utilization of frequency division duplex (FDD) bands is in a paired manner, and it uses a fixed

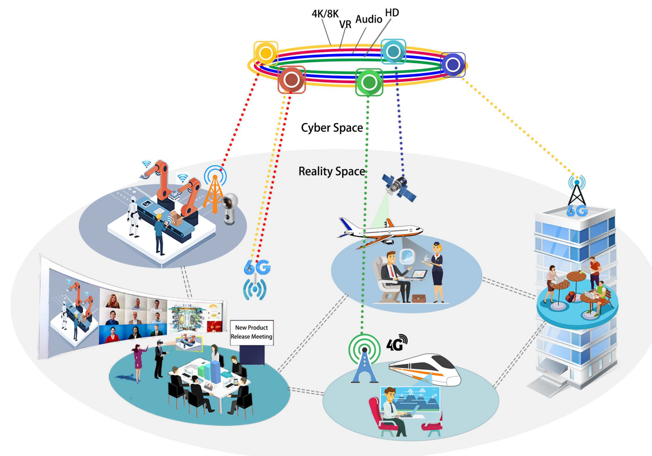

Fig. 1. Scenarios for 6G Applications [4]

978-1-7281-6047-4/20/$31.00 ©2020 IEEE

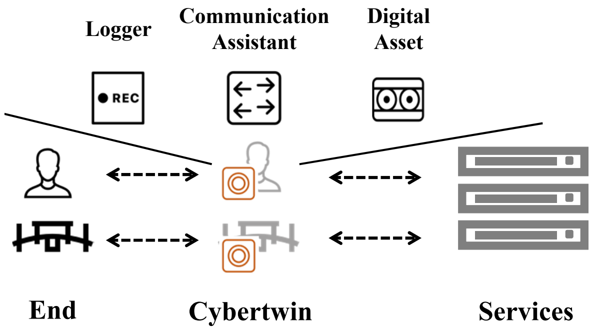

Fig. 2. Cybertwin based communication [6]

portion of the whole spectrum for a particular purpose, i.e., uplink (UL) or downlink (DL), which lacks flexibility and efficiency. Although the spectrum utilization of time division duplex (TDD) bands is in an unpaired manner, it also has some limitations. The guard intervals for UL/DL transition can make the operators' available cellular frequency bands fragmented and lead to spectrum waste. There is also an additional delay induced from waiting for particular UL/DL slots. These limitations require a new radio access network architecture flexibly and efficiently use spectrum resources.

- **New Mechanisms for privacy and data market:** Privacy and security are never the primary considerations of the design principles of the Internet. Companies (such as Google and Amazon) and the underground industry have already shown how valuable users' behavior data are. Whether they obtain the owners' permission to collect this private information or not, they all utilize these data against the owners' interests in many ways, and the owners cannot control how these data are used, let alone to gain profits.
  Thus, 6G should provide some mechanisms to protect private business and personal data. The owners could have the capability of full control and manage their private data with a simple interface. There also must be a data market for owners to sell their data to gain profits [2].
  On the other hand, in the 6G era, there are hundreds of billions of IoT devices connect to the Internet, which poses further challenges to network security. The reason is that these small "things"/devices have limited power and memories which cannot deploy intelligent security strategies. Thus, the network should also provide some kinds of embed trust and security.

To meet these requirements, in this paper, we intoduce a cybertwin based network architecture for 6G. By introducing cybertwin, which serves as a communications assistant, network behavior logger, and digital asset manager of humans and things in the 6G network, we introduce a new communication model and present a new network architecture that consists of a new cloud-centric Internet architecture as well as a novel radio access network architecture.

II. Cybertwin based Network Architecture for 6G

In the proposed cybertwin based architecture for 6G, we introduce a cybertwin based communication model and propose a new cloud-centric Internet architecture as well as a novel radio access network architecture.

A. Cybertwin based Communication model

As mentioned above, the current Internet paradigm cannot meet the requirements of the future mobile network. In the current Internet, the IP address means both the identity and locator of the device [7]. This ambiguity makes the Internet cannot deal with the dramatically increasing demands of mobile devices and services, which lead to the scalability problem. For the network trustworthiness and security, the current Internet relies on the safety of the end-to-end physical connections and supposes that the users are trustworthy. There is no mechanism to authenticate anonymous users, which results in many security issues [8]. For the quality of service (QoS) guarantee, the current Internet only considers how to manage the communication resources and leave the management of computing and caching resources to other entities. It makes the coordination of these resources more complicated. Thus, in [6], we propose a new cloud-centric Internet architecture, which follows a new cybertwin based communication model rather than the end-to-end communication model.

Cybertwin is the digital representation of the end (e.g., humans and things) in the virtual cyberspace locating at the edge cloud, which is the central role of the cybertwin based communication model. Cybertwin can provide three functions, i.e., communications assistant function, network behavior logger function, and digital asset function, to satisfy many new requirements of network design.

With the end-to-end communication model, an end device should establish an end-to-end connection to the server which offers the services. As shown in Figure 2, with the proposed cybertwin based communication model, the ends, which refer to humans and things in the physical network, should first connect to its cybertwin. Then, the cybertwin will obtain the required service from the network on behalf of the end and then deliver the service to the end. This is the **communications assistant functions** (the most fundamental function) of the cybertwin. Acting as the digital representation of the ends, cybertwin can obtain and log all data on behalf of users, which is the **network behavior logger function** of the cybertwin. Then, cybertwin can convert the users' behavior data into a digital asset for sale after removing sensitive information, which is the **digital asset function** of the cybertwin.

B. Cloud-Centric Internet Architecture

Figure 3 shows the proposed cloud-centric Internet architecture. To allow the evolutions of other layers and the incremental updates of the legacy network infrastructure, we still use the IP layer as the "thin waist" of the stack. Above the IP layer, we introduce two new network infrastructure components, that is, **core cloud** and **edge cloud**. There are several core clouds fully-connected with each other to provide

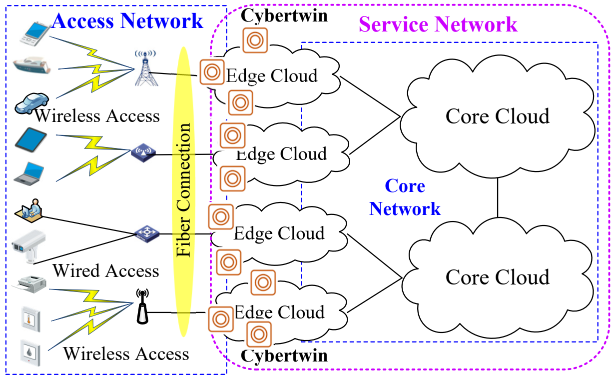

Fig. 3. Cloud-Centric Internet Architecture [6]

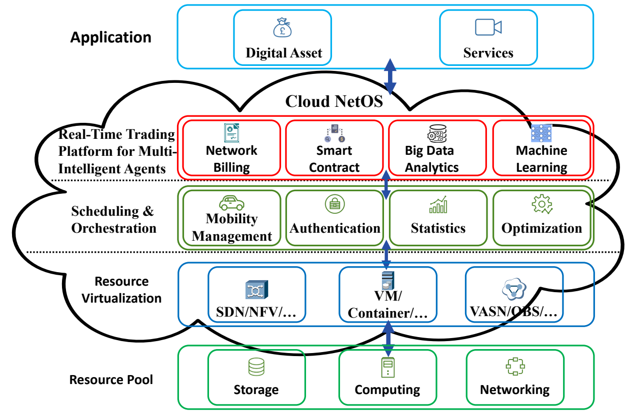

Fig. 4. Cloud Network Operating System [6]

computing, caching, and communications resources for the ends as a network infrastructure service. Residing between the core clouds and the ends, the edge clouds can help the core clouds to make a faster response to the ends' request.

In the new Internet architecture, we introduce a new **cloud operator**, which builds a cloud network operating system, as shown in Figure 4. It can schedule and orchestrate computing, caching, and communications resources coordinately. It also can establish a real-time trading platform for the ends to purchase multi-dimensional resources according to its scarcity.

Based on the network services provisioned by cloud operators, the **application service providers** can deploy their services in the edge and core clouds to form a service network. By doing this, the application service provider can reduce their operational cost as they on longer need dedicated servers and can offer better QoS to users.

C. Cybertwin-Enabled Network Functions

Cybertwin can enable/enhance various network functions, such as locator/identifier split, embed security, and privacy data market. The requirement of locator/identifier split has proposed for many years but has not been widely deployed. The cybertwin based communication model divides the communication process into two-phases. Only the cybertwin can directly access the services deployed in the cloud. Thus, we can use the network address of the cybertwin as a locator, which is opaque to the external network, and use object identifier to identify humans, devices, and services (data and apps). The equipment inside the network does not need to deal with the end's identifier, which can facilitate the implementation of the locator/identifier split.

Another obstacle for locator/identifier split implementation is the lack of an identity authentication mechanism, which helps the network to confirm the user's identifier that he claims is not fake. With the proposed communication model, the ends need to obtain services through cybertwin, which can employ authentication mechanisms to verify the ends. On the other hand, cybertwin logs all users' behavior data, which can be used to determine whether the users' behavior is consistent.

This can also be beneficial to embed security. As the network can confirm the user's identifier, it is easy to punish malicious behaviors. As every data sending to the end should traverse the cybertwin, the cybertwin that is locating at the edge cloud can deploy more advanced security solutions even if the end has every limited computing and storage resources.

The cybertwin can also help to protect users' privacy. In the current Internet, companies acquire the users' behavior data and may abuse them without the permission of the ends. However, as the digital representation of the ends, cybertwin can hide the users' identifier to the application service providers, which can protect users' privacy.

What is more, cybertwin can convert the users' behavior data into a digital asset after removing sensitive information. By establishing a data market, users can trade their digital assets with all interested companies, some of which have no way to collect enough users' behavior data in the current Internet. This data market not only can benefit users but also can motivate innovations as the data is no longer grasped by a few companies. The interface for users to do this is simple as they can empower the cybertwin to make the deal for them.

D. The Fully-Decoupled RAN Architecture

As we cannot increase the frequency bands and decrease the cell size indefinitely, we should design a way to use the scarce spectrum resources flexibly. Thus, we propose a disruptive fully-decoupled RAN (FD-RAN) architecture in which network functionalities are fully decoupled and deployed by independent physical network entities in [4].

1) Decoupling Control Plane and User Plane Physically: The comparisons among the designs of RAN in 4G, 5G, and our FD-RAN is shown in Figure 5. The concept of separating the control plane and the user plane has been applied to a variety of fields. 5G core network defines a service-based architecture (SBA) [9] to put it into practice. However, at the 5G RAN side, each BSs still need to handle both the control functions (e.g., access and mobility functions) and user plane functions (i.e., data transmission). In our proposed cybertwin based network architecture, at the core network (the cloud-centric Internet architecture) also follows the control-user plane separation feature. Furthermore, we argue that, in FD-RAN, we should distinguish the control BSs, which

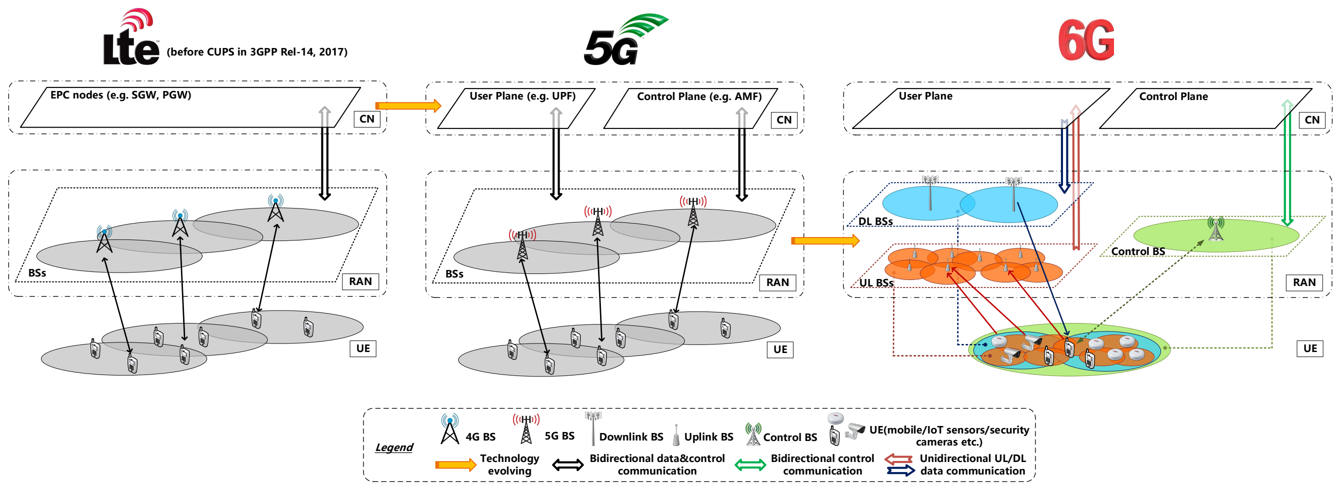

Fig. 5. The Fully-Decoupled RAN Architecture [4]

perform the control plane functions, and the data BSs, which implement the data plane functions.

In the FD-RAN, a control BS works as a macro BS covering a large area where there are several data BSs operate as micro BSs. The user equipment (UE) connects to the control BS through a dedicated low-frequency FDD control channel (by reusing the legacy 2G/3G infrastructures or spectrum resources), which can achieve the low-latency control signaling exchange between UEs and the network. Through this control channel, UEs can receive control signaling from the control BS and report their states and requirements to the control BS. By collecting the feedback information from UEs, the control BS can obtain the network state, which can help it to make control decisions. The control BS also connects to all data BSs within the same area to config high-level control decisions/policies. Guiding by these policies, a data BS performs fine-grained resource control and delivers the data for UEs connected to it. By doing this, we can coordinate the control BSs and Data BSs to manage the spectrum resources in different dimensions and granularity.

2) Decoupling Uplink and Downlink Physically: As mentioned above, in the FDD usage pattern, the spectrum resources are fixed to be used for UL or DL, while in the TDD usage, there are guard intervals for UL/DL transition, which can lead to inefficient use of the spectrum resources. To solve this issue, in the FD-RAN, we decouple data BSs into DL BSs and UL BSs, which are used to transmit downlink and uplink user data, respectively. As we can use any piece of the spectrum for transmitting either uplink or downlink data, the control BS can coordinate the spectrum resources in a realtime and precise way, which can reduce the interference among users and use network resources elastically and effectively.

Another potential benefit of decoupling UL and DL BSs comes from the fact that UL and DL links are asymmetric. As the power limitation of UEs, FD-RAN should deploy UL BSs in an ultra-dense manner to make them close enough to UEs to reduce less path loss and energy consumption suffered by UEs. Typically, DL BSs will consume much more power to transmit a large amount of data. If we do not decouple UL and DL BSs, all BSs will consume a huge amount of power. By decoupling UL and DL BS, we can deploy a much smaller number of DL BSs which have high power to serve a large area. Thus, the total power consumption of all BSs is more efficient due to the reduction of the number of DL BSs and the low power consumption of UL BSs. Therefore, with the proposed fully-decoupled RAN architecture, both the UE side and the network side will consume less energy.

E. Elastic Resource Cooperation in FD-RAN

In the FD-RAN, we can achieve elastic resource cooperation through centralized resource management and multipoint coordinations. The control BS of FD-RAN coordinates DL and UL BSs in a centralized way, which shares a similar idea with the cloud RAN (C-RAN) architecture [10] but performs more flexibly. It forms a large spectrum pool by aggregating the freed spectrum resources from each data BSs and uses these resources to transmit data in an elastical way. By collecting the network state information in a realtime way, the control BS can turn off some DL/UL BSs with few users and low traffic demands to save energy, and allocate the freed spectrum resources to other BSs. As we also redesign the Internet architecture to cloud-centric, the FD-RAN can obtain more cloud resources to utilize.

Coordinated multipoint (CoMP) refers to a series of different techniques to dynamically coordinate the transmission and reception of multiple geographically separated sites to provide higher system performance and better QoS [11]. As shown in Figure 6, the proposed FD-RAN makes it easy to implement the CoMP more flexibly and efficiently as the full separation of UL/DL BSs and with the help of the dedicated control BS.

In the FD-RAN, multiple UL and DL BSs can connect to a UE, and the one with the best performance will serve it. By taking advantage of coordination among different UL and DL BSs, the FD-RAN can manage full-dimensional resources,

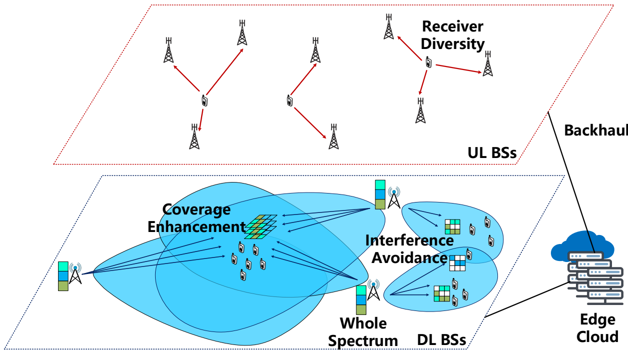

Fig. 6. CoMP in FD-RAN [6]

including time, space, frequency, power, coding, etc. With such a full dimensional resource collaboration, the FD-RAN can reduce the complexity of resource scheduling and achieve better user's QoE. It also can adopt some advanced distributed and coordinated transmission mechanisms such as interference avoidance, receiver diversity, and inter-cell coverage enhancement. As CoMP and multi-connectivity become the default transmission and association schemes, respectively, the concept of a traditional cell no longer exists as multiple BSs can serve a UE. Thus, FD-RAN can provide higher transmission efficiency and reliability, and can support fast mobility.

Based on all features of FD-RAN mentioned above, we design a mechanism to manage interference among data BSs and UEs on both UL and DL sides. The mechanism can reduce interference by separating different transmission directions (i.e., UL/DL) and different transmission nodes (i.e., BSs/UEs) through using multi-dimensional resources including time, frequency, space, code and power For example, in the area with high traffic demand, FD-RAN can adjust the direction and width of the beam towards the area. It can also mitigate inter-cell interference through the coordination of resource utilization patterns among DL BSs.

III. Conclusion

In this paper, we have introduced a cybertwin based network architecture for 6G consisting a new cloud-centric Internet architecture and a novel radio access network architecture, which follows a new network paradigm. Several critical issues still require further research.

- **Data Privacy Protection and Security:** Cybertwin is able to obtain all privacy data about the ends and convert the data into a digital asset, which can make profits for users. However, data management is a critical issue that requires legislation support, e.g., General Data Protection Regulation in Europe [12].
- **Cybertwin based multi-party realtime resource allocation in FD-RAN:** In FD-RAN, resource allocation is challenging as cross-layer (including PHY, MAC, and transport layers) resources need to be allocated among users with diverse demands. Meanwhile, the network resource is always scarce and needs to be allocated dynamically to achieve optimal utilization.
- **Efficient Cloud Network Operating System:** In our cybertwin based network architecture, a cloud network operating system that can coordinate multi-dimentional resources is essential. It should work in a distributed way for efficiency. A potential way is to establish a real-time trading platform for multi-agents (i.e., the ends, telecommunications operators, applications service providers, and cloud operators.)

References

[1] B. Zong, C. Fan, X. Wang, X. Duan, B. Wang, and J. Wang, "6g technologies: Key drivers, core requirements, system architectures, and enabling technologies," *IEEE Vehicular Technology Magazine*, vol. 14, no. 3, pp. 18–27, 2019.

[2] U. of OULU, "Key drivers and research challenges for 6g ubiquitous wireless intelligence," *6G white paper*, 2015.

[3] P. Yang, Y. Xiao, M. Xiao, and S. Li, "6g wireless communications: Vision and potential techniques," *IEEE Network*, vol. 33, no. 4, pp. 70–75, 2019.

[4] Q. Yu, H. Zhou, J. Chen, Y. Li, J. Jing, J. Zhao, B. Qian, and J. Wang, "A fully-decoupled ran architecture for 6g inspired by neurotransmission," *Journal of Communications and Information Networks*, vol. 4, no. 4, pp. 111–117, December 2019.

[5] S. Abdelwahab, B. Hamdaoui, M. Guizani, and A. Rayes, "Enabling smart cloud services through remote sensing: An internet of everything enabler," *IEEE Internet of Things Journal*, vol. 1, no. 3, pp. 276–288, 2014.

[6] Q. Yu, J. Ren, Y. Fu, Y. Li, and W. Zhang, "Cybertwin: An origin of next generation network architecture," *IEEE Wireless Communications*, vol. 26, no. 6, pp. 111–117, December 2019.

[7] L. Zhang, D. Estrin, J. Burke, V. Jacobson, J. D. Thornton, D. K. Smetters, B. Zhang, G. Tsudik, D. Massey, C. Papadopoulos *et al.*, "Named data networking (ndn) project," *Relatório Técnico NDN-0001, Xerox Palo Alto Research Center-PARC*, vol. 157, p. 158, 2010.

[8] C. M. Medaglia and A. Serbanati, "An overview of privacy and security issues in the internet of things," in *The internet of things*. Springer, 2010, pp. 389–395.

[9] E. Dahlman, S. Parkvall, and J. Skold, *5G NR: The next generation wireless access technology*. Academic Press, 2018.

[10] A. Checko, H. L. Christiansen, Y. Yan, L. Scolari, G. Kardaras, M. S. Berger, and L. Dittmann, "Cloud ran for mobile networks—a technology overview," *IEEE Communications surveys & tutorials*, vol. 17, no. 1, pp. 405–426, 2014.

[11] J. Lee, Y. Kim, H. Lee, B. L. Ng, D. Mazzarese, J. Liu, W. Xiao, and Y. Zhou, "Coordinated multipoint transmission and reception in lte-advanced systems," *IEEE Communications Magazine*, vol. 50, no. 11, pp. 44–50, 2012.

[12] S. Wachter, B. Mittelstadt, and L. Floridi, "Why a right to explanation of automated decision-making does not exist in the general data protection regulation," *International Data Privacy Law*, vol. 7, no. 2, pp. 76–99, 2017.