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Challenges of System-Level Simulations and Performance Evaluation for 5G Wireless Networks

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ABSTRACT With the evaluation and simulation of long-term evolution/4G cellular network and hot discussion about new technologies or network architecture for 5G, the appearance of simulation and evaluation guidelines for 5G is in urgent need. This paper analyzes the challenges of building a simulation platform for 5G considering the emerging new technologies and network architectures. Based on the overview of evaluation methodologies issued for 4G candidates, challenges in 5G evaluation are formulated. Additionally, a cloud-based two-level framework of system-level simulator is proposed to validate the candidate technologies and fulfill the promising technology performance identified for 5G.

INDEX TERMS 5G, system-level simulations, performance evaluation, two-level simulator.

I. INTRODUCTION

With the popularization of smart devices and rapid development of internet services, it has been predicted that the traffic flow of mobile data traffic will increase a thousand-fold till the year of 2020. On one hand, as video and audio services are becoming more and more popularized nowadays, the high definition and bigger volume characteristics of graphic and voice services appeal for higher data transmission rate. On the other hand, even with substantially higher transmission rate and traffic flow, perfect user experience are expected to be achieved as the same level with fixed Web access service to meet the real-time demands. The explosive increasing trend of mobile data services and traffic flow motivates new technologies bringing higher spectrum efficiency (SE), higher energy efficiency (EE) and denser cell deployment. Under this background, 5G emerges to introduce advanced key technologies aiming at achieving around 1000 times the system capacity, 10 times the SE, EE and transmission data rate.

In order to satisfy higher speed, more stable and lower end-to-end delay requirements of future wireless mobile communication systems, new network architecture will be adopted. The emerging new technologies like large scale multi-input multi-output (MIMO), Co-frequency Co-time Full Duplex (CCFD), and Carrier Aggregation (CA) are candidate technologies introduced into 5G [1]. In the future, 5G will evolve into a new ultra dense distributed cooperating and self-organized network, with joint radio resource allocation technologies employed by different heterogeneous systems for the purpose of improving resource utilization and system performance.

Nevertheless, this new network architecture and consequent key technologies bring new challenges to system-level simulation methodologies and frameworks for 5G systems adaption. Firstly, from the perspective of internal storage demand and simulation speed, more complex parameter configuration, larger temporal data storage demand, enormous interacting information of users, more diverse performance evaluation metrics appear with the application of large scale antennas [2]. Secondly, traditional network architecture should be updated, which will change the interference distribution situation, the interference calculation becomes more complex and subtle in the new heterogeneous architecture. Thirdly, the distributed coordination and self-organized network make the modification of 4G simulation tools like resource scheduling and beamforming necessary.

On the way towards 5G, organizations, such as the 3rd generation partnership project (3GPP), 3GPP2, International Telecommunication Union (ITU)-2000, all over

TABLE 1. Assessment methods for 4G.

Method	Characteristic for evaluation
Simulation	Cell/Cell edge user spectral efficiency VoIP capacity, Mobility
Analytical	Peak spectral efficiency, Control / User plane latency, Intra- / Inter-frequency handover interruption time
Inspection	Bandwidth and channel bandwidth scalability, Deployment possibility in identified IMT bands, Support for a wide range of services, Inter-system handover.

the world have developed mature system-level evaluation methodologies for 3G, like CDMA2000, WCDMA, long term evolution (LTE). And these simulation methodologies evolved as the pace of standard progressions [3]. In 2008, ITU-R issued International Mobile Telecommunications-Advanced (IMT-Advanced). European project Wireless World Initiative New Radio (WINNER) has provide us detailed evaluation and calibration procedures in line with 4G requirements. 802.16m is also issued by IEEE for the evolution of Wi-Max technology providing systematic evaluation methodologies.

As analyzed above, 5G systems bring new requirements of architecture and advanced technologies, which trigger the emergence of new evaluation framework in both academic and industrial fields. One of the projects currently performed based on 5G is the European Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) project [4]. METIS is scenario-driven and identifies various scenarios with accompanying test cases characterized. With the expected ultra-dense deployment and massive antenna arrays, the runtime of simulation process, including performance evaluation and simulation calibration steps, can be predicted to be seriously extended.

Currently, according to exhibited new features and promising key technologies in 5G networks, the necessary of formulating a heuristic guideline and evaluation methodology to test candidate techniques, investigate new network architecture, research on transmission techniques, is urgent. Under this background, this paper addresses implicit challenges and revisions hidden for 5G system evaluation evolved from existing evaluation reports submitted by different evaluation groups with regard to IMT-Advanced systems.

The rest of this paper is organized as follows. An overview of 4G evaluation methodologies and calibration steps is given in Section II. Then Section III analyzes emerging technologies with respect to architecture and air interface characteristics. The consequent challenges of 5G simulation, brought by new deployments and technologies, are given in Section IV. A new heterogenous computing framework is formulated for the system-level simulator, which introduces the concept of cloud-computing in Section V. Section VI concludes this paper.

II. OVERVIEW ON 4G EVALUATION

A. THE EVALUATION FRAMEWORK OF 4G

According to the evaluation methodologies of ITU [5], the basic evaluation characteristics and assessment methods for 4G are summarized in Table 1 [6]. Among the methods, the simulations, especially system-level simulations, are the most important and complex contents, which cover the largest part of the workload. Figure 1 shows the modular design of system-level simulation together with two-step calibration.

The evaluation setting module implements various ITU test scenarios and provides specific wireless network deployment environment for system operation. The channel model which is calibrated by step1 includes large fading, additive white Gaussian noise (AWGN), MIMO channel and fast fading. The cell topology and user generation is set by the predefined test environments, which are used to specify the environments of the requirements for the technology proposals. Four typical test environments have been chosen such that different deployments are modeled and critical questions in system design and performance can be investigated. Accordingly, to test limits of performance related to capacity and user mobility, the characterized deployment scenarios in evaluation are specified. For each scenario, all configurations (including network layout, simulation parameters, antenna patterns and channel models), necessary to evaluate the performance of radio interface technology, are specified in [5].

The system function module accomplishes required functionality within the framework of the 4G in order to simulate the whole system operation procedure. Since the key algorithm is privately-owned, it has not been formulated by ITU. As each system has its own characteristics, the algorithms should be accordingly adjusted. Power control on the uplink, and scheduling on both the downlink and uplink are some examples in the algorithm. Link adaptation algorithm and interference calculation have been standardized and widely used.

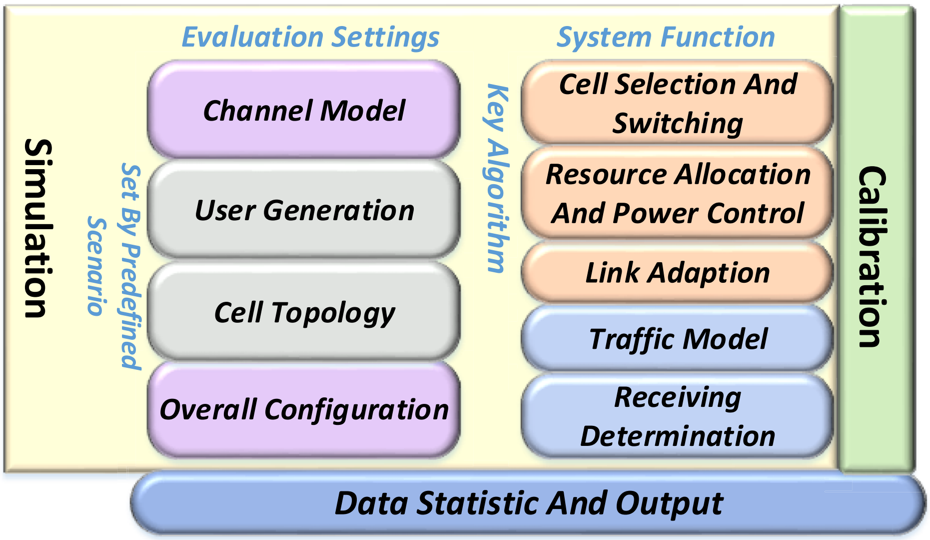

FIGURE 1. System level framework of simulation system for 4G.

B. CALIBRATION STEPS IN LTE-A

As Unified evaluation assumptions and methodology have been described above, in order to facilitate IMT-A evaluations, the simulators from candidate proposers and external evaluation groups should be calibrated before the evaluations by simulations. It makes sure that the results from different evaluation sources are correct, convinced and comparable.

The calibration work of LTE-A includes system-level and link-level parts, and consists of the following steps [6]:

1) Step 1:
   - *Step 1a:* System-level, large scale fading calibration;
   - *Step 1b:* Link-level, link performance in AWGN channel, MIMO fading channel, etc.
   - *Step 1c:* System-level, with a set of simulation assumptions and parameters which are part of current LTE Release 8 (Rel. 8);
   - Right before Step 1c, another calibration step, which is the channel model calibration, is implemented among the members of Chinese Evaluation Group (ChEG).
2) Step 2:
   System-level, implementing LTE Rel. 8 functionality and its extension to testify whether the ITU requirements could be satisfied and to make steps forward;

Among the above-mentioned steps, only large-scale fading is considered in the calculation of signal to interference plus noise ratio (SINR). This step is to compare the distributions of downlink wideband SINR and coupling loss. A set of additional assumptions are made for Step 1a, listed in [7]. In order to calibrate the channel model, step 1b obtain the fast fading channel coefficients based on a step-wise procedure with randomness [5]. The randomness includes the generation of random cluster delays, cluster powers and angles of arrival (AoA) and departure (AoD). The channel model calibration is to calibrate the IMT-A MIMO channel implementation, by comparing the statistics of RMS (Root mean square) of the fast fading parameters including multi-path delays, AoAs and AoDs. Since these parameters in LoS and NLoS (and O-to-I for UMi only) conditions do not have identical expectations and variations, the calibration should be done separately for those cases. The calibration procedures for NLoS and O-to-I cases and those for other scenarios are similar. The related results can be found in [7]. In step 1c, a basic LTE Rel. 8 configuration is given for further system-level calibration [7]. Parts of the Rel. 8 features are implemented in mandatory scenarios with basic models, such as the 12 MIMO antenna configuration and the time-domain Round Robin scheduler. The downlink and uplink spectral efficiencies, user normalized throughput distributions and SINR distributions are compared in the calibration for a basic Rel. 8 configuration. After Step 1, the performances are evaluated to judge if they meet the ITU requirements. Any additional assumptions based on the guideline used in the evaluation should be given together with the results. Common configurations for LTE Rel. 8 and its extensions are listed in [5] with the modeling of control channel overhead.

III. EMERGING TECHNOLOGIES IN 5G

The evolution from 4G to 5G has not been standardized yet, and industrial and academic have not reach a consensus on the ultimate 5G technologies and how to combine these technologies appropriately. There are some emerging and promising technologies, aiming at significantly improving date rates, realizing green communication and perfect user experience, attract much attention. Moreover, the breakthroughs brought by 5G are not limited to this, the explosive growth of mobile traffic data communication implies that the fusion of mobile communication and data transmission will become the mainstream. These technologies can generally be classified into two groups: 1) New air interface characteristics; 2) New network architecture. The emergence of brand new technologies imposes new requirements for 5G simulation and evaluation, next we will begin from analysis of candidate technologies and then give its influence on 5G system-level simulation.

A. NEW AIR INTERFACE CHARACTERISTICS

1) MASSIVE/3D MIMO

Equipping large excessive antennas on the transmit side is firstly put forward by Marzetta in 2006 [8]. The remarkable advantages brought by scaling up MIMO by possibly orders of magnitude compared to current state of art can be summarized on following aspects [2], [9], [10]: 1) Improving spectral efficiency by simply equipping more antennas in current cellular networks and working on multi-user transmission mode; 2) Improving energy efficiency: capable of focusing its emitted energy into a smaller region of space around user locations due to its beam alignment.

Besides, there exists limiting factors if Massive MIMO is incorporated into 5G network, which are under research and discussion. Among these challenges, there are: channel state information (CSI) acquisition [11], pilot contamination [12], [13], new radio propagation characterization [14]. Consequently, under the background of Massive MIMO, the building of 5G system-level simulation evolved from 4G needs to solve the following problems as far as we concerned:

- *Propagation Channel Modeling:* With large scale antennas on BS side, the channel characteristics render differently from traditional channel model;
- *Feedback Bottleneck:* With the predictably huge feedback overhead, (explicitly or implicitly) it's within hot discussion whether to adapt codebook-based feedback or employing a totally new feedback mechanism, for example, compressive sensing based feedback schemes;
- *Operation Mode:* Due to the advantage of utilizing channel reciprocity in TDD mode, which in turn limit the application of Massive MIMO into FDD systems, it has been considered how to settle down the operation modes of Massive MIMO as the combination of TDD and FDD are worked towards an fusion in future networks.
- *Pilot Design:* Due to the scarcity of spectrum resources, adjacent cells tend to transmit their corresponding pilots in the frequency use factor as 1, which leads to serious pilot contamination. This problem could be mitigated by appropriate pilot pattern different from traditional systems;
- *Efficient Processing Ability:* With the deployment of massive antennas, enormous volume data need to be processed at the receive side and infrastructure side, which raise a urgent demand for efficient processing ability in 5G simulation systems.

2) FULL DUPLEX RADIO

Recent advances carried out by researchers at Stanford and Rice attempt to build in-band full duplex radio systems [15]. The implicit improvement in full duplex could be tremendous, due to that the spectrum utilization can be cut down by half or equivalently system capacity achieve twice as before. However, full duplex implementation is predictably difficult due to the unavoidable self-interference since equipment is designed to transmit and receive simultaneously in full duplex radios [16]. Fortunately, recent advances have been made, for examples, NEC labs [17] presents their innovational design work to realize full duplex by analog and digital interference cancelation techniques.

As a promising technology towards 5G realization and standardization, full duplex radio may prove its feasibility. However, there are some obstacles for full duplex radio to overcome [18], [19], for example, additional self-interference calculation circuits should be designed and interference situation becomes more complex. In the case of building a system-level simulation to evaluate full duplex radio, the complex interference situation should be taken into consideration.

- *Complex Interference Situation:* With the introducing of full duplex, serious interference may happen result from: the high DL self-interference to UL signal, the inter-user UL-DL interference, inter-BS DL to UL interference and inter-cell inter-user UL-to-DL interference in multi-cell network;
- *Additional Analog or Digital Circuits:* The influence of designing analog and digital self-interference cancelation circuits should be taken into consideration;
- *Combination With MIMO:* The preliminary method of using full duplex for single transmit antenna and receive antenna has been researched, but the antenna design combining MIMO with full duplex remains a key challenge.

B. NETWORK ARCHITECTURE

1) SMALL CELLS/ULTRA DENSE NETWORK

Future mobile broadband services render new characteristics with the rapid development of mobile internet and smart devices. Firstly, from the view of service types, future broadband services demonstrate features of high speed and huge volume data transmission, all through IP, more diverse services types. Secondly, according to the statistics, the 60 percent and 70 percent of voice services and data services, respectively, happen indoor or in hot spot. Thirdly, from the view of spectrum, spectrum bands tend to be fragmented below 3GHZ, and 3.4GHZ-3.6GHZ spectrum has been allocated to mobile communication in WRC-07, therefore 5G communication are likely to operate on idle spectrum band higher than 5GHZ. All in all, those new trends of future communication prompt small cell network architecture become a necessary topology evolution direction for future data growth [20]. By introducing low-power nodes in heterogeneous networks, significant benefits like enhancement of hot spot, enlarging coverage, improving system capacity, reducing energy consumption can be achieved.

Regardless of benefits brought by small cells deployment, as small cell nodes becomes more dense, the network topology tends to be complicated. This may lead to serious interference problems if the positions of small cells are not reasonably planned. With respect to its influence on system-level simulation, corresponding changes will be made in the following aspects:

- *Interference Calculation Model:* The heterogeneous and ultra-dense network structure determines a totally different interference calculation mode from traditional interference calculation;
- *Additional Clustering:* Clustering methods designed for small cell networks are taken into consideration;
- *Scheduling Method:* The resource allocation algorithms within clusters or among different clusters should be appropriately designed, and evaluations with different allocation mechanisms may differ within a wider range.

2) DEVICE-TO-DEVICE COMMUNICATION

Over recent years, as user distribution becomes denser and communications occur more frequently, proximity based information exchange and connecting have become a major area of interest for mobile internet communication, like social networking, file distribution, and video game. Device-to-Device (D2D) communication, where users communicate directly while remaining controlled under marco base stations, emerges as a promising technology to improve local spectral efficiency and reduce connecting latency [21]–[23]. Compared with traditional 4G cellular network, D2D can afford higher data transmission rate, lower delays and lower power consumption in its local region [24]. The significant benefit achieved relies on that with direct D2D link, multiple wireless hops through routing and BSs are circumvented, which leads to much less latency and interaction signaling resources.

In spite of attempting benefits brought by D2D, there still exists some challenges to overcome when incorporate D2D into 5G. Within relevant discussion of D2D, the challenges include interference coordination, D2D triggering condition and balancing between control overhead and net gains. Firstly, since D2D link reuse cellular frequency resource which causes inter-cell interference. Secondly, net gain achieved by D2D imposes limitations of communication environment, the subtle condition of D2D mode triggering and switching should be determined. Thirdly, building a direct D2D link requires peer discovery and a series of physical layer procedures, which generate extra overheads. From the perspective of system evaluation, with the incorporation of D2D into a 5G system-level simulation, corresponding changes will be made in the following aspects:

- *Interference Calculation:* the introduction of D2D communication changes frequency duplex structure in traditional 4G network, interference brought by D2D links should be taken into consideration.
- *Resource Scheduling:* new resource scheduling schemes need to be carried out mitigating inter-cell interference caused by D2D links.
- *Peer Discovery:* the detailed process of D2D pairs discovery considering real user mobility and distributed management should be added appropriately.
- *Extra Physical Layer Procedures:* channel information of D2D links acquisition requires multiple physical layer procedures like channel estimation and channel feedback.

3) SOFTWARE DEFINED NETWORK

The concept of Software Defined Networking (SDN) is originated by OpenFlow (2008) of Stanford University, where network data plane and control plane are isolated through function abstraction [1], [25]. With separable control planes and data planes, network management can be simplified and previously unavailable services and configurations can be introduced conveniently. In this way, the future network can realize dynamic flexible topology control and afford programming ability to deal with "big data," which is the necessary trend in future communication networks. Although academic and industrial groups have not arrived consensus about the definition of SDN, according to Open Networking Foundation (ONF), SDN is expected to be programmable, open source and flexible. Applying SDN into mobile wireless communication systems can simplify the management of network for commercial operators and endorse the exponentially increasing data flow in foreseen 5G.

Despite that the promised potential SDN brought to provide a fusion of network, data, computation for future networks, communication systems with SDN present relevant challenges [26], [27]. Firstly, how to strike a balance between system performance and flexibility through optimal programmability switch strategy. Secondly, the complexity of standardization and interoperability on the way of transform traditional network to SDN model are still within discussion. What's more, since potential security vulnerabilities exist across the SDN platform, security initiatives need to be carried out to prevent SDN network from malicious attacks.

IV. CHALLENGES IN 5G EVALUATION

Compared to 4G evaluation system, there are more challenges in 5G evaluation system listed as follows:

A. MORE PRECISE PROPAGATION MODELS ARE NEEDED

On the way towards 4G, different channel models have been discussed and formulated into standardization, among which 3GPP, 3GPP2 and WINNER project have recommended spatial channel model/spatial channel model extended (SCM/SCME) and WINNER+ channel models respectively. As issued by ITU, the widely adopted channel model structure for IMT-Advanced consists of a primary module and an extension module [5], and the primary module is origi-

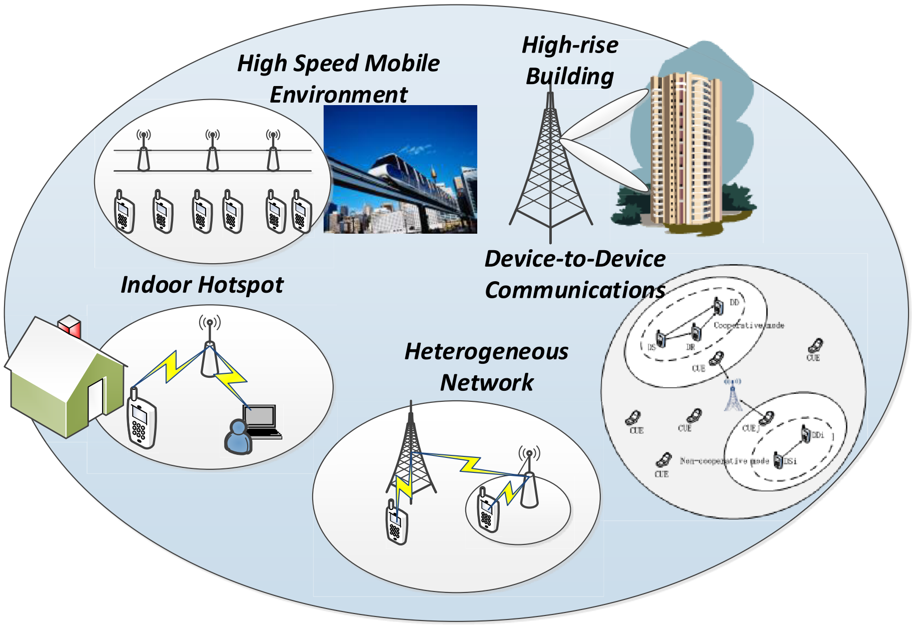

FIGURE 2. Complex and diverse evaluation scenario.

nated from the WINNER II channel model. The recommended channel model considers generally five typical scenarios: indoor hot-spot (InH), Urban micro-cell (UMi), Urban macro-cell (UMa), rural macro-cell (RMa), suburban macro-cell (SMa), with different set of parameters influencing large-scale and small-scale parameters.

Channel propagation exhibit different characteristics in 5G systems due to the adoption of 3D-channel model [28] and enriched propagation scenarios. Different from traditional 2D channel model, the 3D channel modeling consider both the horizontal and vertical spatial characteristic, which exploit the scattering properties of spatial channel to improve the diversity of MIMO. Moreover, taking massive MIMO and ultra dense antenna deployments into account, the channel behavior using large arrays differs from that usually experienced using conventional smaller arrays [2] due to that: 1) There might be large scale fading over the array; 2) Small-scale signal statistics may also change over the array.

B. COMPLEX AND DIVERSE EVALUATION SCENARIOS ARE DEPLOYED

5G tends to cover a wide range of network structures to improve the coverage ratio, which makes the evaluation scenarios more complex and diverse. In 4G systems, there are typical 5 deployment scenarios for evaluation, while in 5G the scenarios have to be extended. Currently, the hottest scenarios concentrate on evaluating the performance of ultra dense network and 3D MIMO system which are two key technologies in 5G. We believe that the following emerging scenarios will be considered in the evaluation of 5G, as depicted in Fig. 2.

- *Heterogeneous Network:* Future network will evolve from homogeneous cellular network to the coexistence of marco-cells with random distributed lower power nodes forming small cells including mirco-cells, pico-cells, femeto-cells.
- *High-Rise Building:* In urban environment, mobile users are tend to distributed in a three dimensional (3D) environment such as office building or shopping mall, therefore the height of high-rise building should be taken into consideration.
- *D2D Communication:* In the era of data, several co-located devices would like to connect to each other for the purpose of sharing videos, pictures or files in social-networking or office environment.
- *High-Speed Mobile Environment:* In 4G communication systems, it's generally perceived that data rates and reliability on fast moving vehicles can not be guaranteed. It is suggested that mobile relay node can be installed on mobile vehicles as well as distributed MIMO base stations to achieve reliable communication quality by coordinated transmission technologies.
- *Traditional Typical Simulation Scenarios:* To fulfill the backward compatibility and smooth evaluation of 5G evolved from 4G, it's important that 5G collaborates typical simulation scenario, like the five typical scenarios in identified in [29] and 3GPP case1, 3GPP case2 adopted in [30].

C. MORE SIMULATION PARAMETERS AND PERFORMANCE METRICS SHOULD BE CONSIDERED

4G evaluation mainly focus on a few performance metric for specific services, such as the capacity of VoIP and the throughput or spectral efficiency under full buffer traffic model. Future services tend to diversify along with each

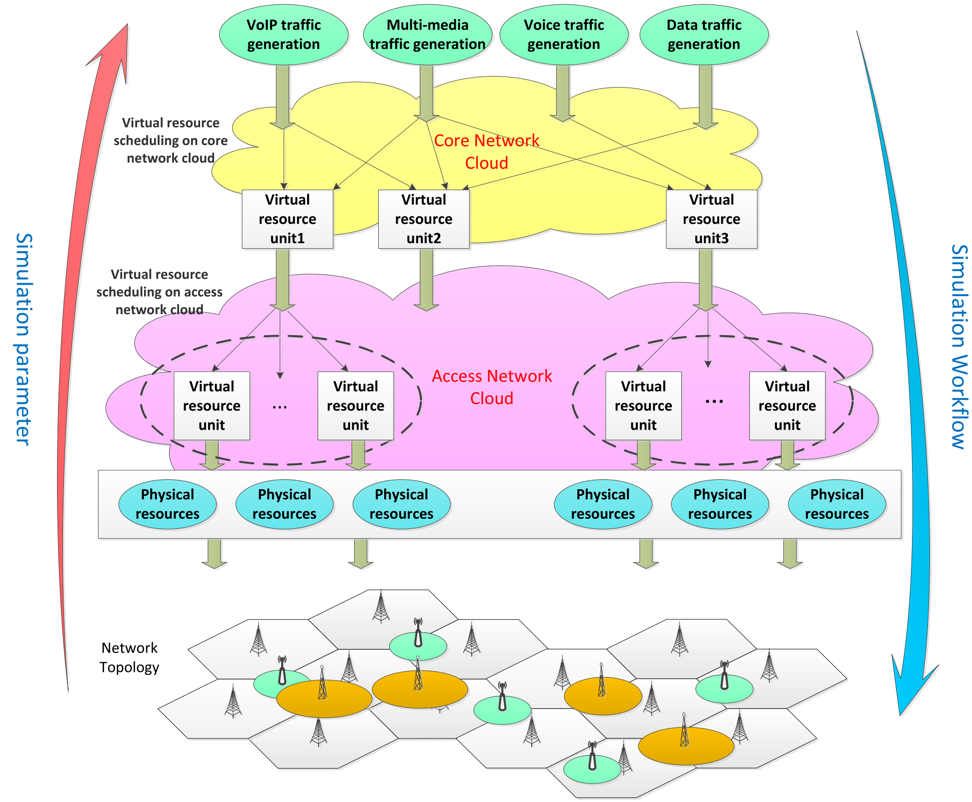

FIGURE 3. Flowchart of a two-level 5G network simulator.

service has its own emphasized metrics and traffic models. For example, explosively increasing mobile service needs large bandwidth and brings a mass of energy consumption. Thus, spectral efficiency and energy efficiency are the emphasized metrics for mobile service. High-definition video (HD video) service requires little delay and high-definition experience, which put forward a very high request to the quality of experience (QoE) and delay of the systems. In order to take all the services into account, 5G system should strengthen the service modeling and synthetically integrated consider a wide range of evaluation metrics such as spectral efficiency, energy efficiency, coverage ratio and QoE.

D. SIMULATION EFFICIENCY BECOMES A BOTTLENECK

As 5G system tend to merge multiple communication standards and diverse network structures, system-level simulation becomes more complex and difficult to implement. Considering the simulation efficiency, single-machine simulation cannot afford to complete the such a huge task. Therefore, three possible solutions are proposed as follows:

- *Multi-Machine and Multi-Core Parallel Simulation:* A large number of repeated and independent computations can be realized by Multi-machine and multi-core parallel simulation instead of traditional methods to effectively improve the simulation efficiency. Guaranteeing the precision of channel and system model, the parallel simulation methods can greatly reduce the simulation time, thus improving the research efficiency.
- *Hardware Acceleration:* There are huge numbers of matrix operations in channel propagation model as well as data transmission and demodulation model, while the existing CPU is more capable of the one-dimensional string-based computing. Such matrix operations can be assigned to graphic processing units (GPUs) because of the its ability in high dimensional matrix computing, hence improving simulation performance under more complex system model.
- *Cloud Computing:* Large amount of data and calculation can be solved in large-scale server cloud, so that each simulation module can access computing ability and storage space according to its own requirement, thus greatly improving the simulation efficiency by the effective use of the server's processing resources.

V. FRAMEWORK OF SYSTEM-LEVEL SIMULATOR

Through out the overview of 4G evaluation and emerging challenges brought by new network architecture and key technologies, building a new system-level simulator for 5G system is in urgent need to validate candidate technologies and fulfill the promising performance identified for 5G. Therefore, in this section, a cloud-based two level network simulation framework is proposed.

Fig. 3 demonstrates the flow chart of a two-level simulator adapted to the future network employment and technologies in 5G. In particular, since the boundaries between core network and access network will be broken in 5G, controlling

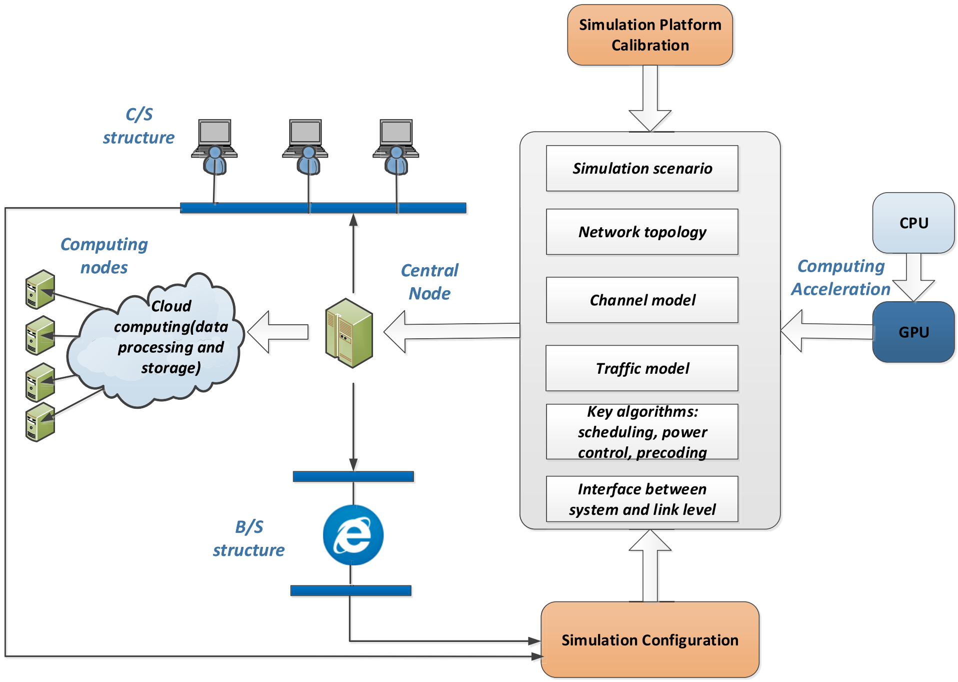

FIGURE 4. Framework of a cloud-based system-level simulation platform.

interface are realized by controller software. With respect to the core network cloud, simulator will simulate behaviors of users, network channel information, uplink traffic type or geographic information. As to the access network, the simulated modules are the service type of accessed users and virtual resource units set. As depicted by Fig. 3, simulator tend to support various traffic model, for instance, voice service, VoIP service, video service and data service. The initiated services are generated on virtual core network cloud side. The simulator will perform two-level source allocation among core network and access network according to designed resource mapping and allocation algorithms. The interface controller software is supposed to separate add implement before unified. Consequently, simulator will map virtual resource units into physical resource units, conduct regular simulation process from topology generation to data transmission and output metric.

Fig. 4 shows a framework of a cloud-based simulation platform to handle the increasing massive data processing and realize self-management in 5G systems. As we can see, GPU as well as CPU is used for computing acceleration. Before evaluation, users can input system configurations through web or installed softwares, which optimizes human-computer interaction and achieve good encapsulation of evaluation simulator. In main body of simulation modules, including simulation scenario, traffic model, channel model, user distribution, interference calculation, key algorithms implementation, interface between link level and system level, corresponding revisions should be made as discussed in Section3 and Section4. It should be noticed that the computing are assigned to various computing nodes, managed by a central unit, which formulated a cloud based simulator. The results of computing and processing are stored on the cloud side, network resources can be dynamic allocated between users according to their demands. With this design, the proposed simulator for the evaluation of 5G acquires the following advantages:

- *Scalability:* The computing nodes on cloud side could be added or deleted according to dynamic demands. The maximum number of computing nodes is determined by data processing and distribution ability of central node.
- *Flexible Resource Calling:* Users could flexibly access to resources on cloud through websites or application software installed.
- *Self-Management:* The management of cloud-based simulation system is transparent to users, different subsystem accomplishes their management automatically given input generated from the previous level.

VI. CONCLUSION

In this paper, we present the challenges of building a simulation platform for 5G brought by emerging new technologies and network architectures. With the introduction of new air interface and network architecture, 5G simulation puts forward a very high request to integration and efficiency. To meet the strict requirements, a cloud-based two-level framework of system-level simulator is proposed. By dividing the system function into layers from the view of system, the two-level simulator will perfectly integrate various simulation scenarios and technologies. Moreover, using cloud computing, simulation efficiency can be greatly improved. Although the benefits of the cloud-based two-level framework of system level simulator are clear and reasonable, the implementation in practice still need indepth research, considering practical constrains.

REFERENCES

[1] W. H. Chin, Z. Fan, and R. Haines, "Emerging technologies and research challenges for 5G wireless networks," *IEEE Wireless Commun.*, vol. 21, no. 2, pp. 106–112, Apr. 2014.

[2] F. Rusek *et al.*, "Scaling up MIMO: Opportunities and challenges with very large arrays," *IEEE Signal Process. Mag.*, vol. 30, no. 1, pp. 40–60, Jan. 2013.

[3] G. Yuehong, Z. Xin, Y. Dacheng, and J. Yuming, "Unified simulation evaluation for mobile broadband technologies," *IEEE Commun. Mag.*, vol. 47, no. 3, pp. 142–149, Mar. 2009.

[4] B. Krzysztof, W. Krzysztof, and R. Marcin. (Mar. 2013). *Simulation Tools for the Evaluation of Radio Interface Technologies for IMT-Advanced and Beyond*. [Online]. Available: https://www.metis2020.com/wp-content/uploads/publications

[5] *Guidelines for Evaluation of Radio Interface Technologies for IMT-Advanced*, document M.2135, Report ITU-R, Dec. 2009.

[6] W. Ying, W. Tan, L. Lisha, and S. Cong, "On the evaluation of IMT-advanced candidates: Methodologies, current work and way forward," in *Proc. 6th Int. Conf. Wireless Commun. Netw. Mobile Comput. (WiCOM)*, Sep. 2010, pp. 1–4.

[7] Updated Calibration Information of Chinese Evaluation Group. [Online]. Available: http://cheg.ccsa.org.cn/Updated%20Calibration%20Information%20of%20Chinese%20Evaluation%20Group.doc, accessed Dec. 14, 2009.

[8] T. L. Marzetta, "How much training is required for multiuser MIMO?" in *Proc. 40th Asilomar Conf. Signals, Syst. Comput. (ACSSC)*, Oct./Nov. 2006, pp. 359–363.

[9] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," *IEEE Trans. Commun.*, vol. 61, no. 4, pp. 1436–1449, Apr. 2013.

[10] J. Hoydis, S. ten Brink, and M. Debbah, "Massive MIMO in the UL/DL of cellular networks: How many antennas do we need?" *IEEE J. Sel. Areas Commun.*, vol. 31, no. 2, pp. 160–171, Feb. 2013.

[11] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive MIMO for next generation wireless systems," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 186–195, Feb. 2014.

[12] J. Choi, Z. Chance, D. J. Love, and U. Madhow, "Noncoherent trellis coded quantization: A practical limited feedback technique for massive MIMO systems," *IEEE Trans. Commun.*, vol. 61, no. 12, pp. 5016–5029, Dec. 2013.

[13] J. Jose, A. Ashikhmin, T. L. Marzetta, and S. Vishwanath, "Pilot contamination and precoding in multi-cell TDD systems," *IEEE Trans. Wireless Commun.*, vol. 10, no. 8, pp. 2640–2651, Aug. 2011.

[14] E. Björnson, J. Hoydis, M. Kountouris, and M. Debbah. (2013). "Massive MIMO systems with non-ideal hardware: Energy efficiency, estimation, and capacity limits." [Online]. Available: http://arxiv.org/abs/1307.2584

[15] M. Jain *et al.*, "Practical, real-time, full duplex wireless," in *Proc. 17th Annu. Int. Conf. Mobile Comput. Netw.*, 2011, pp. 301–312.

[16] D. Korpi, M. Valkama, T. Riihonen, and R. Wichman, "Implementation challenges in full-duplex radio transceiver," in *Proc. 33rd Finnish URSI Conv. Radio Sci.*, Espoo, Finland, 2013, pp. 181–184.

[17] E. Aryafar, M. A. Khojastepour, K. Sundaresan, S. Rangarajan, and M. Chiang, "MIDU: Enabling MIMO full duplex," in *Proc. 18th Annu. Int. Conf. Mobile Comput. Netw.*, 2012, pp. 257–268.

[18] T. Riihonen, S. Werner, and R. Wichman, "Mitigation of loopback self-interference in full-duplex MIMO relays," *IEEE Trans. Signal Process.*, vol. 59, no. 12, pp. 5983–5993, Dec. 2011.

[19] J. I. Choi, M. Jain, K. Srinivasan, P. Levis, and S. Katti, "Achieving single channel, full duplex wireless communication," in *Proc. 16th Annu. Int. Conf. Mobile Comput. Netw.*, 2010, pp. 1–12.

[20] V. Chandrasekhar, J. G. Andrews, and A. Gatherer, "Femtocell networks: A survey," *IEEE Commun. Mag.*, vol. 46, no. 9, pp. 59–67, Sep. 2008.

[21] S. Mumtaz, K. M. S. Huq, and J. Rodriguez, "Direct mobile-to-mobile communication: Paradigm for 5G," *IEEE Wireless Commun.*, vol. 21, no. 5, pp. 14–23, Oct. 2014.

[22] R. Alkurd, R. M. Shubair, and I. Abualhaol, "Survey on device-to-device communications: Challenges and design issues," in *Proc. IEEE 12th Int. New Circuits Syst. Conf. (NEWCAS)*, Jun. 2014, pp. 361–364.

[23] J. F. Monserrat *et al.*, "Rethinking the mobile and wireless network architecture: The METIS research into 5G," in *Proc. Eur. Conf. Netw. Commun. (EuCNC)*, Jun. 2014, pp. 1–5.

[24] K. Doppler, M. Rinne, C. Wijting, C. B. Ribeiro, and K. Hugl, "Device-to-device communication as an underlay to LTE-advanced networks," *IEEE Commun. Mag.*, vol. 47, no. 12, pp. 42–49, Dec. 2009.

[25] P. A. Morreale and J. M. Anderson, *Software Defined Networking: Design and Deployment*. Boca Raton, FL, USA: CRC Press, 2014.

[26] S. Sezer *et al.*, "Are we ready for SDN? Implementation challenges for software-defined networks," *IEEE Commun. Mag.*, vol. 51, no. 7, pp. 36–43, Jul. 2013.

[27] A. Galis *et al.*, "Softwarization of future networks and services-programmable enabled networks as next generation software defined networks," in *Proc. IEEE SDN Future Netw. Services (SDN4FNS)*, Nov. 2013, pp. 1–7.

[28] M. Narandzic *et al.*, "3D-antenna array model for IST-WINNER channel simulations," in *Proc. IEEE 65th Veh. Technol. Conf. (VTC-Spring)*, Apr. 2007, pp. 319–323.

[29] *Requirements Related to Technical Performance for IMT-Advanced Radio Interface(s)*, document M.2134, Report ITU-R, 2009.

[30] "Further advancements for E-UTRA physical layer aspects," 3rd Generation Partership Project RAN1, Tech. Rep. TR 36.814 V9.0, Mar. 2010.

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