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On Big Data Analytics for Greener and Softer RAN

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ABSTRACT Big data analytics applied to signaling, traffic, and wireless environment data in mobile communication networks can help realize autonomous network optimization and build big data-based network operation. In this paper, a signaling-based intelligent network optimization scheme is introduced and applied to the current mobile communication networks, such as 4G Long Term Evolution. In 5G era, big data analytics can help mine user and service requirements from the radio access network level, thus allowing a more efficient 5G design and operation. This paper illustrates how it would significantly facilitate local content provision, dynamical network and functionality deployment, user behavior awareness, fine-tuned network operation, and globally optimized energy saving solutions. It is anticipated that the big data-based 5G network design, and the operation will be greener and softer, and better meet the ever increasing user-centric requirements of mobile communication.

INDEX TERMS Big data, network operation, 5G, user-centric, user behavior sensing.

I. INTRODUCTION

Mobile communication networks provide a great variety of communication services, while simultaneously producing a massive amount of network data. Through current or future data collection platforms, operators can obtain various data of users, services and equipment, including signaling data, network management data, terminal data, service analysis data, user information, service information, parameter information, configuration information, and so on. As the mobile industry moving forward steadily with 4G infrastructure and getting ready for the 5G era, network data is experiencing rapid growth at peta bytes per day scale. It is becoming both an important issue and an opportunity for operators to be able to fully exploit the great value in this data to facilitate the development of efficient communication networks.

Big Data techniques and technologies in data mining and decision making have been rapidly expanding across all science and engineering domains, including physical, biological, biomedical sciences, etc. [1]–[7]. ''Big data'' refers to datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze [8]. The key features of big data are volume (more data), velocity (real time), and variety (diverse data type) [9]. These features match quite well with the characteristics of network data in mobile communication networks.

Making use of available network data, big data techniques and technologies can help operators deploy intelligent operation and maintenance capabilities and customizable private networks. Networks of intelligent operation and maintenance start with collecting, analyzing, and storing a large amount of all around signaling, user, and wireless environment data. Combined with self-organizing network technologies (SON), it would enable full scale automatic network optimization, thus facilitate network deployment and centralized optimization. By collecting and analyzing user behavior and network status data, customizable private networks can deliver customized network configurations and service push, and meet the architectural and functional flexibilities required in future networks, while providing a higher efficiency and quality of mobile communication services. The next section will present a specific application of big data analytics deployed in our 4G network, whereas the section afterwards will consider various applications of big data analytics in the future 5G network design.

II. APPLYING BIG DATA TO IMPROVE PERFORMANCE AND EFFICIENCY OF THE CURRENT NETWORKS

The essence of big data-based intelligent and green 4G network operation and maintenance is to build a performance optimization platform based on a totality of network data. Applying big data technologies, the system analyzes the Long Term Evolution (LTE) network from multiple dimensions and provides optimized solutions.

We start with such a platform. The relevant data sources in a LTE network include, but are not limited to, Signaling

Software-collection Data, Signaling Hardware-monitor Data, User-plane data, Terminal data, and data from operation and management center. The platform architecture is divided into three layers: the Data Collection Layer, the Data Sharing Layer, and the Application Layer. All of the information is collected by the Collection Layer. The Sharing Layer performs Data Extraction, Data Sorting, Data Analysis, Data Amalgamation, and Data Statistics. Many different application tools constitute the Application Layer. With this platform architecture, the system can be transplanted and expanded easily. One of the important functions on its Application Layer is the full scale signaling data based intelligent network optimization As shown in Fig. 1, it collects original signaling data from the myriad interfaces of mobile networks. After the association and backfill operations, the signaling data record will be formed as an XDR (External Data Representation) and the signaling-plane analysis for network optimization can be carried out. The signaling data based intelligent network optimization consists of three major steps:

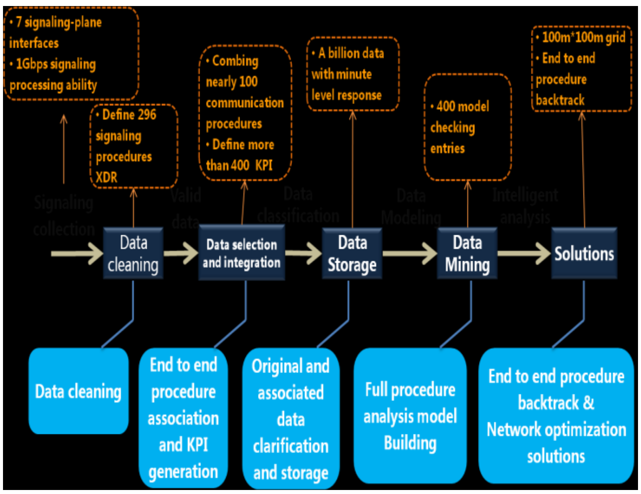

FIGURE 1. Flow chart of the signaling data based intelligent network optimization.

A. EXTRACT XDR KEY WORDS TO DEFINE THE NETWORK PERFORMANCE INDICATORS

The XDR is defined according to the signaling process, therefore it contains the key information of the signaling, such as the types of signaling and the causes of the process failure. The XDR also identifies the status of complete signaling processes, such as the success or failure of a signaling establishment and release. Based on this information, a number of network performance indicators are defined. And these indicators can be queried from multiple dimensions and levels, such as the cell, user, and grid levels. The time resolution can reach minute level currently.

B. DISCOVER NETWORK PROBLEMS THROUGH NETWORK PERFORMANCE INDICATORS

XDR-based network performance indicators can reflect comprehensive network signaling-plane status, such as the service establishment success rate, the drop rate, the handover success rate, and so on. These indicators directly reflect the network performance. We can further analyze the network equipments whose performance indicators are unsatisfactory, mainly through further excavation of the original signaling of the corresponding indicators. For example, if the drop rate of a cell is high, we can further analyze the main causes of the high drop rate, and try to solve the problem associated with the most likely cause. For example, if we find that the high drop rate is mainly caused by factors A and B, with 90% and 5% likelihood respectively, then the network problems are most probably caused by factor A.

C. PROVIDE BEST PRACTICE SOLUTIONS BASED ON OPTIMIZATION EXPERIENCE FOR IDENTIFIED PROBLEMS

Based on optimization experience, we can classify a variety of network problems. For example, if a cell's handover success rate is low, according to the definition of the associated indicators, it is caused by the low success rate of handover preparation. We can then adjust the overlapping coverage areas between the source and the target cells, and parameters such as the handover initiation, the decision threshold, offset, and hysteresis. As another example, if a cell's E-RAB establishment success rate is low, and through further analysis we find the cause is related to the transmission resources, then we should examine whether the physical transmission configuration of the cell is adequate.

In summary, the signaling data based intelligent network optimization forms the signaling XDR through the original signaling collection, analysis, correlation, and synthesis. Define an array of network performance indicator sets from the XDR, analyze unsatisfactory indicator sets, further fine-tune the indicators and deep dive in the original signaling, and finally lead to solutions to pinpoint network problems. Moreover, based on the original signal in the network from each signaling interface, single-user signaling tracking and backtracking queries can be accomplished. It is easily realized through user information and time as input, then query for matched XDR record and its original signaling process mapping.

A whole suite of signaling data based network optimization analysis tool with the platform described above is being developed. Together they provide the entire network performance monitoring, real-time queries, and key indicators presentation. Once any indicator deteriorates, one could click the index query which has caused the deterioration of the indicators and get a recommended solution.

Figures 2-5 give an example of utilizing such a platform in a typical scenario identified in Guanzhou last year. It found deterioration of the indicators of the success ratio of evolved packet system (EPS) cell attach through XDR data calculation, as shown in Figure 2.

By clicking on the deteriorated indicators, it could find that the reason for the low success ratio of attach is the time of the EPS cell attach failure (the failure is due to rejection), as shown in Fig. 3.

时间	小区	EPS附着成功率(%)
2014-09-19 00:00...	广州天河区猎德安置...	
2014-09-18 22:00...	广州天河区珠江西路...	
2014-09-18 20:00...	广州天河区石牌复建...	100
2014-09-19 03:00...	广州天河区石牌西路...	
2014-09-19 06:00...	广州天河区育蕾小区...	
2014-09-18 17:00...	广州天河路F-ZLH-1	100
2014-09-19 10:00...	广州天河路F-ZLH-1	
2014-09-18 22:00...	广州新中轴隧道E-ZL...	
2014-09-19 11:00...	广州正佳南（搬迁）...	
2014-09-18 22:00...	广州海正电脑城F-ZL...	
2014-09-18 17:00...	广州海正电脑城F-ZL...	100
2014-09-19 01:00...	广州海正电脑城F-ZL...	
2014-09-18 23:00...	广州海正电脑城F-ZL...	
2014-09-19 06:00...	广州猎德污水处理厂...	
2014-09-18 16:00...	广州珠江公园西北F-...	75

FIGURE 2. EPS attach success rate.

时间	小区	EPS附着请求次数	EPS附着失败总次数	EPS附着失败次数(拒绝)
2014-09-18 16时	广州珠江公园西北F-ZLH-1	4	1	1

FIGURE 3. The analysis of low EPS attach success rate.

	开始时间	结束时间	终端类型	流程类型	流程状态	关键字	eNB ID	ECI
1	2014-08-18...	2014-08-18...	HUAWEI D2-5000	附着	成功	EPS/IMSI联合附着	172207	17220701

FIGURE 4. XDR drill of EPS attach failure.

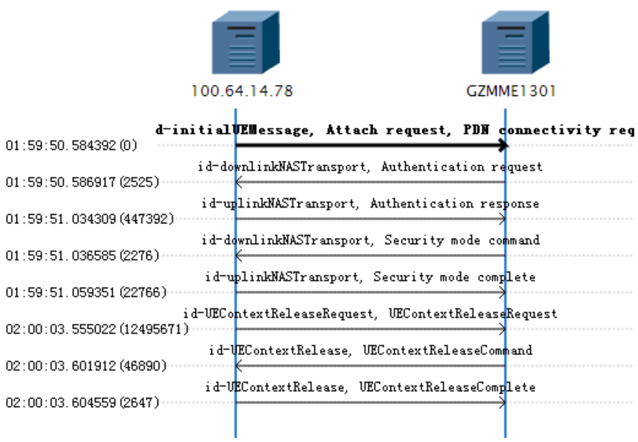

FIGURE 5. The backtrack of EPS signaling attach process.

By clicking on the failure time, it could drill the corresponding XDR data, as shown in Fig. 4.

Following the XDR drill, the original signaling process could be traced, as shown in Fig. 5. Based on the failure reason value brought by the Attach-Reject parameter in the original signaling process, it could evaluate and determine the failure reason and provide a solution advice.

III. BIG DATA APPLICATION AND 5G NETWORK DESIGN

In order to better meet the future requirements of mobile Internet and Internet of Things, efficiency and agility are crucial to 5G, thus green and soft are the essential themes [10]. In addition to a higher data rate and lower latency, user experience enhancement is also a key goal of 5G system [1]. Therefore, a flatter network architecture, flexible functionality and topology, smart user and traffic awareness, and highly efficient low cost network operation are expected to be key elements of user-centric 5G access network design.

- ✧ *Flatter Network Architecture:* Content awareness can facilitate local caching & content provisioning, local switching and local breakout to meet the "0" latency requirement.
- ✧ *Flexible Functionality and Deployment:* To match diverse scenarios in 5G, it is necessary to provide flexible access point deployment and functionality. It may include supporting diverse access points, plug and play access points, and functionality slicing, among other things.
- ✧ *Smart User and Traffic Awareness:* To better meet diverse user requirements of the mobile Internet, the 5G system needs to adapt services and user requirements based on user behavior awareness.
- ✧ *High Efficient Low Cost Network Operation:* In addition to a higher data rate and lower delay, the operation cost efficiency requires flexible and self-organized operations.

A. BIG DATA BASED LOCAL CONTENT PROVISIONING

Personalized local content provisioning is an important target for the user-centric 5G network. It includes: user and service awareness at the RAN side, local caching and management.

The access network used to be user and service agnostic, which is a "blind pipe" connecting the user to the core network. In order to meet critical 5G requirements, such as low latency and user-centric requirements, the access network needs to be user and service aware. It will help facilitate local content provisioning, which is a key technology in 5G. Big data analysis will help mine and predict user requirements with the information from the network. And then the requirements are checked locally if they can be met via local content.

Local caching and management are the basis to fulfill local content provisioning via monitoring and analyzes of source traffic, providing a local copy. It can help reduce end to end latency and enhance user experience.

- ✧ *User and Traffic Information Acquisition:* The first step is to collect traffic attribute via packet analysis, which may include the application type (FTP, HTTP, etc.), server address, port number, traffic content, etc. Then this data is analyzed comprehensively via clustering algorithm, e.g., K-means [11], [12], which is a basic distance based clustering algorithm series; LDA (Latent Dirichlet Allocation) [13], which is a three layers (document-topic-word) model to label the traffic; for instance sports news, entertainment video, or a romance/action movie.
- ✧ *User Requirement Analysis and Prediction:* The big data analysis algorithm, especially recommendation algorithms, e.g. Collaborative Filtering [14], will

recommend contents that the user may be interested in, for example a romance movie, by considering traffic labels, user attributes, terminal types, etc.

- *Local Caching and Content Management:* The popular content is to be copied locally, as in the case of a downloaded movie, or to be downloaded from the application server and cached locally, as in the case of a sports news, by matching the traffic labels with the content users may be interested in.
- *Content Provisioning:* On the one hand, when the user initiates an application request, the system will check whether the corresponding content is already locally cached and thus can be sent directly. On the other hand, according to the content recommendation via big data analysis, the system will check if it is cached locally and push to the user directly.

B. BIG DATA BASED FLEXIBLE DEPLOYMENT AND FUNCTIONALITY

Big data algorithms can be used to analyze regional user and service characteristics to help facilitate flexible network and functionality deployment.

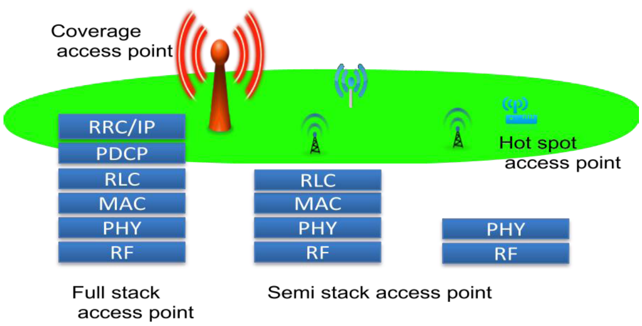

FIGURE 6. A paradigm of flexible network deployment.

1) FLEXIBLE NETWORK DEPLOYMENT

As shown in Fig.6, diverse low cost access points (APs) are to be supported in 5G, such as coverage APs which guarantee the coverage, and hot spot APs which fulfill the high throughput requirements in certain area, full stack APs and semi stack APs. Big data algorithm can help analyze and predict the traffic characteristic, providing the basis for realizing dynamical network deployment.

For example, firstly, the regional traffic distribution trend and characteristics is analyzed via big data algorithms, e.g., LDA, with collection of traffic and user attribute. Then the hot spot APs will be deployed (such as plug and play) or turned on according to the results of the analysis to meet the throughput requirement of hot spot in a certain period of time.

2) FLEXIBLE FUNCTIONALITY DEPLOYMENT

Software and hardware decoupling of network equipment is the fundamental of flexible functionality deployment. Big data algorithms can help analyze and predict regional user and service requirements, which is the basis of dynamic functionality deployment.

For example, the regional user and service requirements are analyzed via big data algorithms, e.g., Collaborative Filtering [14], with user and traffic information. Then the corresponding network functionality module will be deployed according to the analysis, such as to deploy Multimedia Broadcast Multicast Service (MBMS) functionality module in areas where there is much broadcasting requirement, to deploy device to device (D2D) functionality module in areas where there is group communication requirement, and to deploy safety functionality module in areas where there is high requirement of security.

C. BIG DATA BASED USER BEHAVIOR AWARENESS

Wireless resources need to be optimized according to user and service requirements in 5G to improve efficiency and the user experience. It is found that a 93% potential predictability in user mobility (route and time) across the whole user base by studying the mobility patterns of anonymized mobile phone users [15]. As shown in Fig.7, some users often get on the train at a certain station via subway or high-speed rail, and get off at another station. The motion trajectory can be predicted via big data analysis to pre-configure the network.

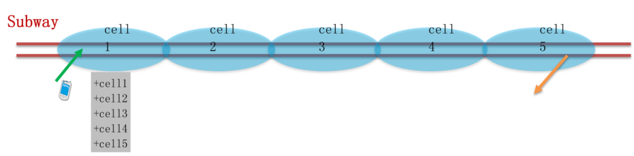

FIGURE 7. A paradigm of user behavior awareness.

The APs will record the historical AP list of each user, and directly upload it to a central processing module, or to a target AP when the serving AP is changed. Then the collected user motion data is analyzed to predict the motion trajectory via the big data algorithms. As shown in Fig.7, when AP 1 (cell 1) get the predication that the user motion trajectory is from cell1 to cell 5 via cell 2, 3, and 4, it will send the configuration of cell 2, 3, 4, 5 to the corresponding terminal to facilitate pre-configuration of these cells.

D. BIG DATA BASED HIGH EFFICIENCY NETWORK OPERATION

The Big Data based network operation system includes: traffic sensing, user capability sensing, centralized & personalized functionality management and distribution, unified wireless platform, among other modules.

Fig. 8 shows a paradigm of big data based network operation. It includes user information collection and strategy making which belong to decision making domain, as well as UE context management and function configuration which compose implementation domain. The system is divided into two parts: the decision making domain and the implementation domain. The decision making domain is mainly responsible for the collection and management of user information, as

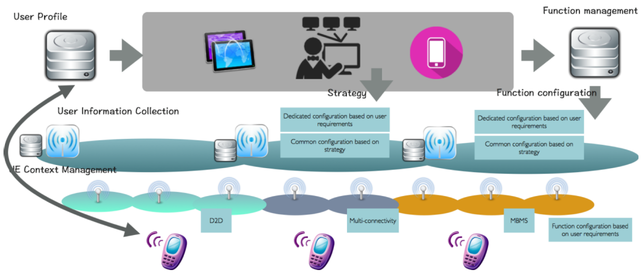

FIGURE 8. A paradigm of big data based network operation.

well as service and terminal state, network upgrade, selection, configuration and unified management, etc. The implementation domain is responsible for the user, terminal and network status reporting, network configuration and dynamic deployment, etc.

The decision making domain provides the basic configuration via big data analysis to initialize the network. Then the decision making domain chooses and deploys the functionalities and APs which meet the user requirements. The implementation domain will build multi-connectivity bearers with terminals via dynamic APs, functionality and configuration according to the requirements after receiving the personalized configuration.

The efficiency of the big data based network operation can be maximized, through optimal resource allocation (frequency, time, antenna, power, etc) to each AP and to each user, such that the required service is provided from the optimal set of APs with optimally allocated resources. For example, in the 5G ultra dense deployment scenario, it may be a problem for users to have too many neighbor cells, which may be redundant and consume too much unnecessary power, and sometimes interfere with each other. To resolve this issue, big data algorithms can help analyze user and service requirements with the collection of network status. Then the system can choose the corresponding configuration of neighboring cell according to the analysis. For example, it is possible that not all the APs support downlink 256QAM. If a service needs the downlink 256QAM functionality, only those APs with this functionality will be configured as the neighboring cells, with remaining neighboring cells turned off for power saving. The decision making domain needs to have the whole picture of functionality distribution in the network and the requirements of users and services. The implementation domain configures the terminal according to the command from the decision making domain to fulfill user-centric neighboring cell configuration.

E. BIG DATA BASED MULTI-RAT OR HetNet ENERGY SAVING

In multi-RAT or HetNet mobile networks, for energy saving purposes, certain small cells may enter into dormant state when the aggregate traffic is below a predefined threshold. Existing users within the coverage areas of the dormant cells would be served by nearby small cells via cell breathing or directly served by the corresponding umbrella macro cell [19]. The following small cell activation schemes have been specified in [20].

- ✧ *Operation, Administration and Management (OAM) Based Scheme:* The macro cell will schedule small cells in its coverage to be On or Off according to the traffic load gathered by the OAM system.
- ✧ *Interference Over Thermal (IOT) Ratio Based Scheme:* When the traffic load of the macro cell exceeds some threshold, the macro cell will request some "Off" small cells to turn on and measure their uplink IOT ratios. Small cells with sufficiently high ratios will be activated.
- ✧ *UE Measurement Based Scheme:* When the traffic of the macro cell exceeds some threshold, the macro cell will request some "Off" small cells to enter into "probe" mode in which the small cells would transmit downlink reference signals. The macro cell will then request UEs to measure the reference signals from the small cells in "probe" mode and feedback the measurement results. The macro cell will then decide if and which small cells should be activated.

There are drawbacks in the energy saving schemes above. These schemes operate under a relatively long time scale and hence fail to adapt closely to the dynamic temporal and spatial traffic variations. When new UEs or mobile UEs during handover attempt to access the network where cell activation is required, the corresponding small cells needs to be activated first, and then operate normally, e.g. transmit the broadcast information and downlink reference signals. UEs will only then be able to access the network per standard procedures. This process might lead to an unacceptable latency for the UEs to access the cells of the best match.

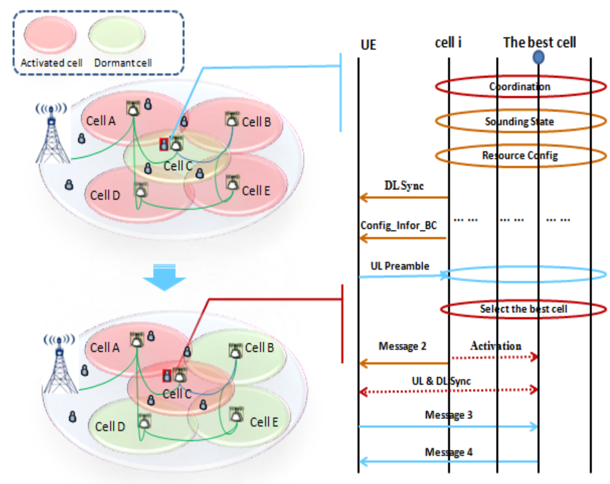

FIGURE 9. Energy saving with big data based network entry.

With big data analytic, small cell activation and UE access to the network can be optimally implemented, as illustrated in figure 9. This will bring much enhanced access latency and achieve the maximum energy saving possible according to dynamic traffic variations. The detailed procedure of the big data based user-centric network entry is as follows:

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- ✧ The macro cell and small cells have coordinated resource allocation for uplink sounding in the uplink probe mode, in which all the cells need to monitor the uplink signals from UEs. This can be done semi-statically.
- ✧ Based on the uplink random access signals of new UEs or UEs with handover requirement, also based on the traffic variation of the existing UEs in the network, the central controller will decide whether some dormant small cells need to be activated and whether some activated small cells need to enter into dormant mode.
- ✧ Upon receiving the mode transition request (to 'probe'), the dormant cells and the already activated cells will start uplink probe procedure and monitor the uplink reference signals with the dedicated uplink probe time and frequency resources. These resources are aligned among all the adjacent cells and broadcast to UEs.
- ✧ The UEs will synchronize in the downlink and choose the cell with the best downlink channel and acquire the dedicated uplink probe resources allocation via broadcast.
- ✧ Then all the cells including the macro cell will monitor the uplink reference signals from UEs on the dedicated uplink probe resources. Based on the uplink measurement results and traffic load of each cell, the central controller will determine which dormant small cell to activate, which activated small cell should be dormant, and which cell each UE should access. The decision will be transmitted from the cell which was selected by each UE for the downlink synchronization and broadcast information acquisition. The uplink parameter adjustment information for each UE with the best cell will also be conveyed.
- ✧ UEs will then access to the best cell based on the received information.

As shown in figure 9, cell A, B, D, E are activated, while cell C is dormant before the arrival of the UE of interest. Then, after the above procedure, only cell A and cell C are activated, while the remaining three cells are dormant. This roughly results in a 50% reduction of base station power consumption. In the traditional HetNet or multi-RAT scenario, a new UE's access to the network is generally based on the measurement results of downlink reference signals. The UE will choose one proper cell for initial network entry. For the big data based user-centric network operation, UEs' access and energy saving can be jointly optimized.

Multi-RAT Cooperation Energy-saving System (MCES) is developed by China Mobile to improve network energy efficiency by collaborative operation in a multi-RAT scenario with GSM, TD-SCDMA and Time Division Long Term Evolution (TD-LTE). As shown in figure 10, the MCES system is composed of three functional modules: data collection module, policy decision module and execution module. In the data collection module, the network information and user information, such as users' QoS and location, network configuration and traffic data, will be collected. Policy decision

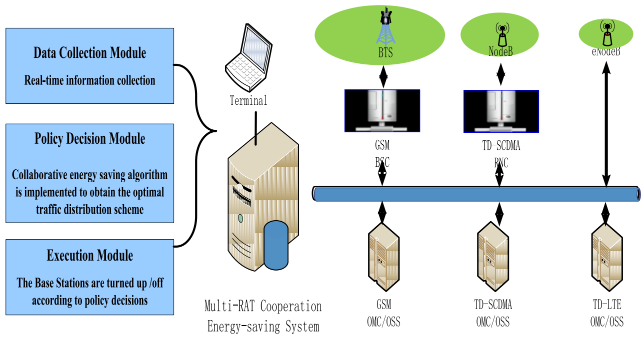

FIGURE 10. Multi-RAT Cooperation Energy-saving System (MCES).

module will run the collaborative energy saving algorithms to obtain the optimal traffic distribution scheme. Finally the execution module will issue the turning on/off orders to the cell in time. According to the field test results, MCES could achieve 20% energy saving for every cell.

F. COMPRESSIVE SENSING TO EASE BIG DATA ACQUISITION IN 5G

One major limiting factor to 5G big data is the acquisition of all the necessary data, e.g. signaling, user data, and wireless channel state information (CSI) etc. 5G networks are expected to be ultra-dense with significantly increased number of base stations, antennas and terminals. This will naturally lead to extremely high overhead in CSI measurement and feedback. One potential solution to ease big data acquisition is sparsity exploration, e.g., compressive sensing (CS) [17], which is a breakthrough in signal processing. CS technologies encode sparse signals by using far lower sampling rates than the classical Nyquist rate by exploiting the signal sparsity, thus significantly reducing the incurred overhead. The motivation behind applying CS in 5G is that more and more experimental evidence suggests that many kinds of signals in wireless communications are sparse or compressible in some transform domains (e.g., sparse channel, spare user activity, sparse spectrum unitization, etc.), especially in the ultra dense 5G networks. It's anticipated that the adoption of sparsity exploration design into 5G may significantly alleviate the burden of complex signaling and data processing in the ultra-dense 5G networks, and facilitate big data processing.

IV. CONCLUSIONS

In this paper, the application and perspective of big data analysis in mobile communication network is discussed. A signaling data based intelligent network optimization scheme is first introduced for existing networks. Then the application of big data in 5G is investigated, which helps to achieve flatter network architecture, flexible network and functionality deployment, smart user and traffic awareness, and highly efficient network operation with lower energy consumption and lower cost. According to the analysis, big data analytics will play a critical role in making mobile communication networks more agile and efficient, i.e., soft and green.

The data volumn to be analyzed in the mobile communication network may be quite challenging in the future. By the end of 2015, the data volumn to be analyzed per day in one operator's network will be about 6.8 PB. In 5G era, the volumn will be even greater. Big data algorithm with relative low complexity for high volume data, such as distributed matrix [18] will be particularly attractive. More understanding of the network data classes will be essential as well.

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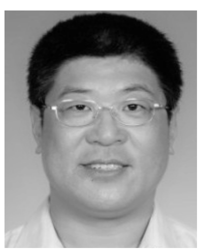

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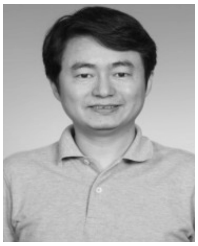

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