Modeling and Simulation of IMT-2020(5G) Systems and Satellite Communication Systems Based on OPNET Network Simulation Technology

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***Abstract*—Network simulation is a new technology of network design and optimization. Using coexistence analysis between IMT-2020 (5G) systems and 25.5-27GHz band Earth Exploration-Satellite Service (EESS) systems as examples, this paper introduces modelling, simulation and Electromagnetic Compatibility (EMC) analysis methods based on OPNET. The modeling processes are illustrated closely. Compared with the protection criterion, the two services can coexist based on a certain distance. The models can be used for network planning, design and performance analysis in the following research. This paper shows the new method of EMC analysis and new application of network simulation technology.**

Keywords-OPNET; network simulation technology; IMT-2020(5G); EESS; modelling; aggregated interference power

I. INTRODUCTION

Network simulation technology is a method to simulate network behavior by using mathematical modelling and statistical analysis, so as to obtain the specific network performance parameters. It can be used for network planning, design, transformation, and principle experiment, especially for large and complex network. OPNET [1] is one of the most popular network simulation and development software, based on hierarchical modeling method, packet modeling mechanism, discrete event driven mechanism model, rich model library, completely open systems, abundant statistics collection and analysis capabilities.

As we all know, spectrum source is limited source. As radio service developed, the spectrum demand is increasing more and more. In order to improve spectrum utilization, radio management department considers allocating the spectrum of existing services to new ones. For example, some spectrum bands on 24.24-86GHz band will go to IMT-2020(5G) while satellite communication service has already worked in this bands. In order to ensure satellite communication service can work normally and make full use of spectrum resources, the coexistence analysis between two services needs to be done.

There are few existing models about IMT-2020(5G). The models need to be established by the researchers based on system parameters provided by Recommendation ITU-R M.2101 [2]. And the modelling of satellite communication systems needs to solve the problem that Earth Station's (ES) elevation angle is changing with satellite's movement. Supporting new models' establishment, wireless communication and satellite communication, OPNET is suitable for this case.

Using EMC analysis between IMT-2020 (5G) systems and 25.5-27GHz EESS [3] systems as examples, the models of wireless communication systems and satellite communication systems are established based on OPNET, which are the preparation for the EMC analysis and network planning, design, performance research for the next research. The results are useful for research and development, providing new method and new application for network simulation technology.

II. SYSTEMS

A. OPNET Platform

As a main network simulation software, OPNET provides a comprehensive simulation development environment for communication networks and distributed systems [4]. OPNET analyzes the behavior and performance of various simulation systems by performing discrete event simulation. OPNET integrates the tools needed in each simulation phase to form a large simulation system that combines model design tools, simulation cores, data collection tools and data analysis tools.

OPNET has the following characteristics:

1) Hierarchical modeling method

Modeling should be made from bottom to top respectively at the process layer, the node layer, and the network layer. The network model is the highest level, consisting of network node and communication link. The topology structure can be established in this layer. The node model consists of module and connections, such as physical interface module, IP module, data packet flow. The network device models can be established in this layer, reflecting devices' characteristics. Each module corresponds to one or more process model. The process model describes the internal operation mechanism and response process by the finite state machine through the C programming language. The three layer models are completely corresponding the actual network, device and protocol layer, and reflect the related characteristics of the network.

2) Packet modeling mechanism

OPNET is used to simulate the actual packet flow (packing & unpacking) in physical network based on packet

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processing, including flow between network devices and processes in network devices internal.

3) Discrete event driven simulation mechanism

OPNET uses discrete event driven simulation mechanism. The “event” means network status’ change. The simulation is carried out only when the network status changes. The simulation would be skipped when the status does not change. The event information is transmitted through interrupt method between modules.

4) Completely open systems

All the source code in OPNET is open to the users. The users can add or modify the existing source code, which provides great convenience for the user’s research and development.

5) Abundant statistics collection and analysis capabilities

OPNET provides interactive running debugging tool, powerful results analyzer and dynamic observer which can observe models’ behavior in real time. The users can set parameters before simulation, and interrupt the simulation at any time. The statistical data is shown in result analyzer in graphical ways, and also can compare multiple simulation results, providing a powerful evidence for decision-making.

TABLE I. IMT-2020(5G) SYSTEM PARAMETERS

Item	**Parameters (BS)**	**Parameters (UE)**
Antenna height(m)	6	1.5
Antenna array configuration (Row × Column)	8x16	4x4
Sectorization	Single sector	
Downtilt and pointing	-10ºto UE	To BS
Antenna pattern	ITU-R M.2101	
Element gain（dBi）	5	
Horizontal/vertical 3 dB bandwidth of single element	65º for both H/V	
Horizontal/vertical front-to-back ratio (dB)	30º for both H/V	
Antenna polarization	Linear ±45º	
Horizontal/Vertical radiating element spacing	0.5 of wavelength for both H/V	
Array Ohmic loss (dB)	3	
Conducted power per antenna element (dBm/200 MHz)	10	
BS maximum coverage angle in the horizontal plane	120º	
Deployment area	50 km^2	
Network loading factor	50%	
TDD activity factor	80%	20%
Density (BS/km^2)	30（urban）,10（suburb）	
Transportation Model	ITU-R P.452 [5]，ITU-R P.2108-0 [6]	
Hotspot coverage ratio(Ra)，Built-up area ratio(Rb)	Ra=7%(urban), 3%(suburb), Rb=100%	

Notes: this paper only considers BS TDD activity factor=100%, UE TDD activity factor=0%, and urban（Ra=7%） conditions.

B. IMT-2020(5G) Communication Systems

IMT-2020(5G) communication systems are still in the research stage in 24.25-86GHz at present. The systems include micro Base Station (BS) and User Equipment (UE). The parameters of IMT-2020(5G) in this paper refer to recommendation ITU-R M.2101 (shown in Table I).

C. 25.5-27GHZ EESS Communication Systems

The EESS communication systems need to receive data from GSO satellites and Non-GSO satellites. So this paper establishes two systems-GSO communication systems and Non-GSO communication systems. EESS systems include ES and satellite. The parameters are shown in Table II.

TABLE II. GSO/NON-GSO SYSTEM PARAMETERS

Item	**GSO**	**Non-GSO**
Satellite’s trajectory	105E	FY-3
ES location	116.3E，40.1N	130.3E，46.7N
Height（m）	10	
Carrier frequency（MHz）	26760	26703.4
Bandwidth（MHz）	452	300
Antenna radius（m）	7.3	
ES antenna gain toward satellite（dBi）	61.4	64.4
ES antenna receiving polarization	RHCP	
ES antenna pattern	ITU-R S.580 [7], ITU-R S.465-6 [8]	
ES receiving noise temperature（K）	433	363

III. MODELLING

Firstly it needs to establish model library of IMT-2020(5G) systems and EESS systems. Then set network topology. The models should be established in Process layer, Node layer, and Network layer in OPNET.

A. Modelling of IMT-2020(5G) Systems

The structures of BS and UE in process layer and node layer are established in the same way [9]. The node layer consists of “process”, “tx&rx”, “ant” and “point” modules. The “process” module which consists of “init”, “active wait” and “generate” processes controls message transmitting and receiving. The “tx&rx” modules represent transmitter and receiver. The “ant” module controls antenna pattern which will be calculated and loaded. The “point” module which consists of several different processes controls antenna pointing. The antenna patterns are calculated by MATLAB and loaded into “ant” module based on different functions of models.

The models of them are shown in Fig. 1 and Fig. 2:

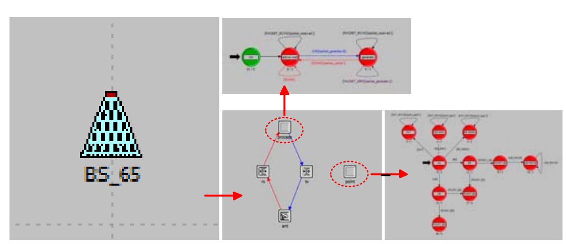

Figure 1. Model of BS.

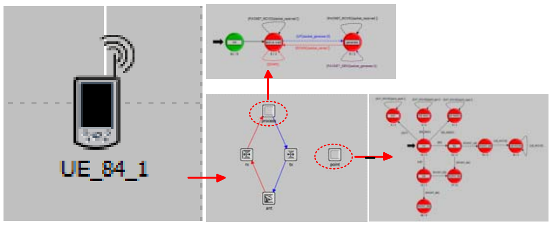

Figure 2. Model of UE.

B. Modelling of GSO/Non-GSO Systems

The ES models include GSO ES and Non-GSO ES. The satellite models include GSO satellite and Non-GSO satellite. The satellite's trajectories are established by STK software based on orbit data and loaded.

The models of them are shown in Fig. 3 and Fig. 4, and the satellites' models are shown in Fig. 5 and Fig. 6:

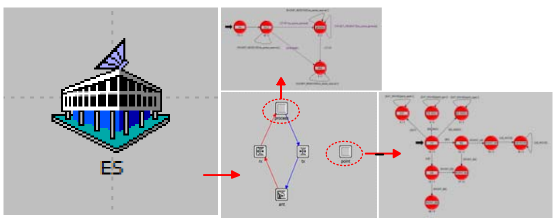

Figure 3. Model of GSO/Non-GSO ES.

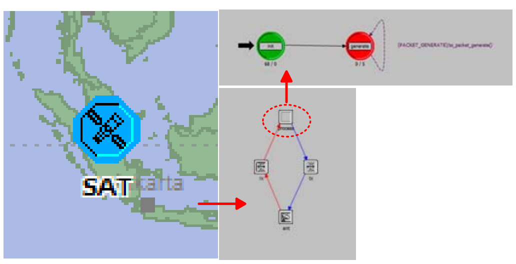

Figure 4. Model of satellite.

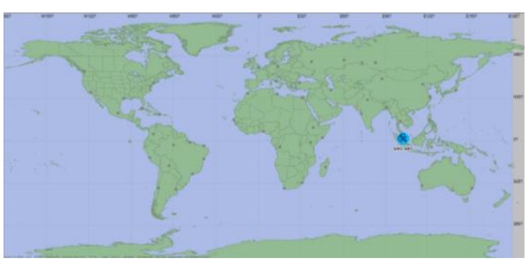

Figure 5. GSO satellite's trajectory.

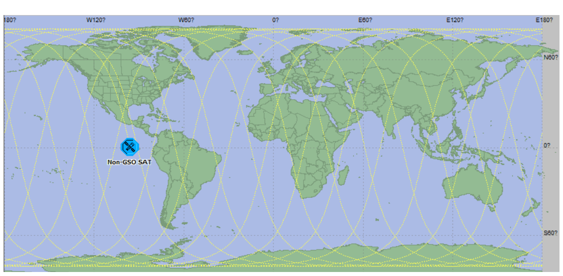

Figure 6. Non-GSO satellite's trajectory.

C. Modelling of Antenna Patterns OPNET Platform

Firstly the 180*360 polar and azimuth values in degrees were calculated based on Recommendation ITU-R M.2101, ITU-R S.580, ITU-R S.465-6. Then the 2D/3D antenna patterns were drawn in OPNET. The data of antenna patterns are loaded into "ant" module based on different functions of models. The models are shown in Fig. 7- Fig. 10:

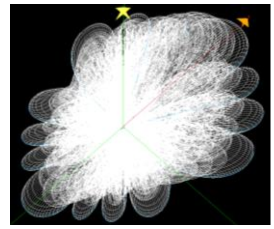

Figure 7. Antenna pattern of BS.

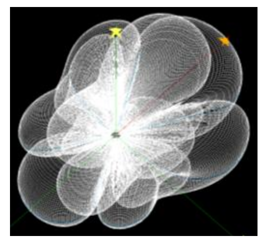

Figure 8. Antenna pattern of UE.

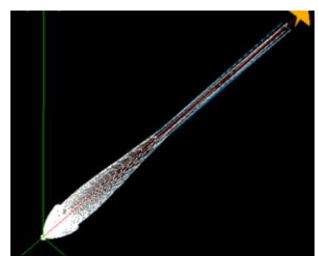

Figure 9. Antenna pattern(GSO ES).

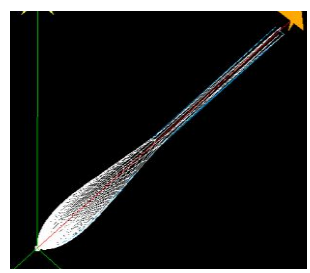

Figure 10. Antenna pattern(Non-GSO ES).

D. Interference Topology from IMT-2020(5G) BS / UE to EESS

In the case of the aggregated interference, the deployment of IMT BSs and UEs is as Fig. 11 shows. It should be noted that IMT-2020 networks will only be deployed in a hotspot area and not as seamless coverage. Some areas will not deploy IMT systems. Taking the outdoor IMT scenario as an example, the number of IMT BSs is Ds*Ra*Rb, which Ra=7% (urban), Rb=100%.

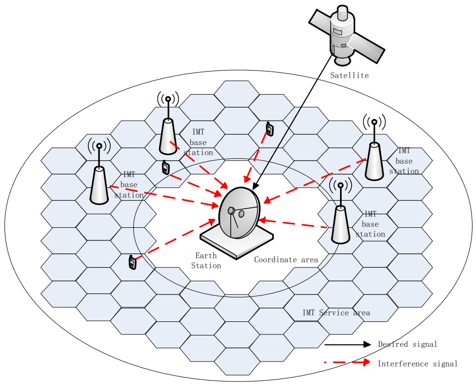

Figure 11. Aggregated IMT BSs/UEs scenario.

The calculation of the aggregated interference power from multi IMT-2020(5G) micro BSs and UEs deployed in a given distance from the EESS earth station is as follows:

$$I_{agg} = 10log\left(\sum_{n=1}^{n=N} 10^{I_n/10}\right)$$

where, I_{agg}: aggregated interference power received by the earth station (dBW); I_n: interference power from the nth IMT BS/UE (dBW).

IV. Simulation

1) Set the topology of equally-spaced IMT BSs and UEs located around the EESS earth station (Fig. 11). Use "deploy wireless network" in the OPNET to deploy the network topology rapidly. The deployment area of IMT-2020(5G) systems is about 50km^2. The BS's density is 30 BS/km^2. The total number of BSs is 1543. The protection distance is defined beforehand about 1km. So the total number of BSs is 1543-61=1482. The network loading factors of BSs=50%. So max active number of BSs in a built-up area = Ds * Ra *Rb=1482*50%*7%*100%≈52.

2) Set service parameters. The BS's antenna main lobe direction mechanically declined 10 degrees and points to UE. UE's antenna main lobe direction points to BS and it moves freely in the cell. ES's antenna main lobe direction points to the satellite and varies with the satellite's movement. When ES's antenna main lobe direction points to GSO satellite, the elevation angle between ES's antenna main lobe direction and horizontal plane is changed in a small scale, the communication link will be always established all the time. When ES's antenna main lobe direction points to Non-GSO satellite, the elevation angle between ES's antenna main lobe direction and horizontal plane will be changed in the range of 0^o-90^o. When the elevation angle $<5^o$, the communication link cannot be established, the ES stops communicating with satellite. The other parameters refer to Table I and Table II .

3) Set pipeline parameters. OPNET supports dynamic modelling of wireless link. The wireless link consists of 14 pipeline stage. In this simulation scenario, it mainly needs to set BS/UE's transmitting antenna gain stage, and ES's receiving antenna gain stage, receiving power model stage, ecc model stage. The receiving power model stage, ecc model stage are set as follows: open signal lock, all the packets transmitted from BSs/UEs would be received by ES. The aggregated interference power is all the packets plus.

4) Collect statistical results [10]. Set the aggregated power received by ES receiver as global network performance statistic to reflect the interference condition of ES.

A. Co-channel Interference from IMT Systems to GSO Systems

The simulation results are as Fig. 12 shows. The simulation time should last enough to get enough data. The simulation time is 4days.

B. Co-channel Interference from IMT Systems to Non-GSO Systems

The simulation results are as Fig. 13 shows. The Non-GSO satellite trajectory is periodical. The simulation time is 20days in order to get enough data.

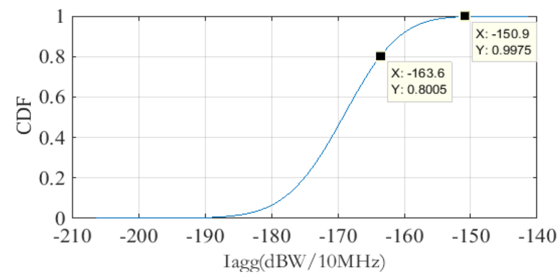

Figure 12. CDF plot of aggregated interference power(GSO ES).

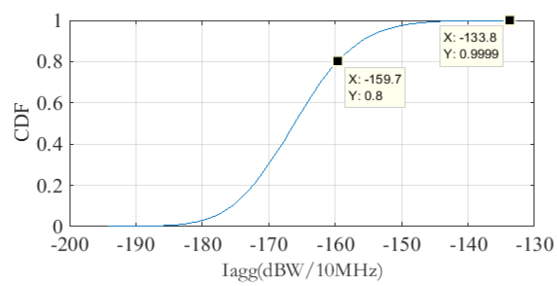

Figure 13. CDF plot of aggregated interference power(Non-GSO ES).

TABLE III. Interference Criteria for Stations in the EESS and Satellite Service Using Spacecraft in the Geostationary Orbit and Low-Earth-Orbit

ITEM		**Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time (dBW/10MHz)**	**Interfering signal power (dBW) in the reference bandwidth to be exceeded for no more than p% of the time (dBW/10MHz)**
GSO	Criteria	<-144.6	<-133 (p=0.25)
	Simulation result	-163.6	-150.9
Non-GSO	Criteria	<-143	<-116 (p=0.005)
	Simulation result	-159.7	-133.8

C. The Protection Criterion of GSO/Non-GSO Systems

According to ITU-R SA.1160-3 [11] and SA.1027-5 [12], the protection criterion is shown in Table III.

Compared with protection criterion, the aggregated interference power received by GSO ES and Non-GSO ES in the simulation do not exceed the protection criterion whether no more than 20% of the time or p% of the time. It means that the IMT-2020(5G) and EESS systems can coexist based on the same frequency band when the protection distance is 1km.

V. CONCLUSION

Based on research of OPNET network simulation technology, combined with the examples of EMC analysis of IMT-2020(5G) system and EESS system, this paper discussed the application of network simulation technology in EMC analysis. The research shows that network simulation technology is suitable for wireless communication modeling, satellite communication modeling and EMC analysis. And the models of IMT-2020(5G) systems and satellite communication systems established in OPNET will be used in network planning, design and performance analysis in the follow-up research. It avoids repeated modeling for network simulation research. This paper provides a new method for EMC analysis and a new application for network simulation technology.

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