Received May 31, 2016, accepted June 6, 2016, date of publication August 26, 2016, date of current version January 27, 2017.
Digital Object Identifier 10.1109/ACCESS.2016.2602318

Interference Reduction by Millimeter Wave Technology for 5G-Based Green Communications

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This work was supported by the Ministry of Science and Technology, Taiwan, under Grant MOST 103-2221-E-197-019.

ABSTRACT The primary goal of this paper is the optimization of data transmissions and connections between 5G base stations (BSs) as well as the improvement of access technologies and transmission methods in consideration of massive multi-input multi-output, a key technology in 5G networks. In order to reach an access technology supported by multiple BSs and small cells, we use 5G millimeter wave (mmWave), due to its high directivity and sensitivity to blockage, to enhance the connection system. In the simulation, we will consider extremely high-frequency band and small angle of mmWave, and arrange obstructions in the environment in view of high attenuation characteristics in mmWave signals. After a wave beam penetrates through a wall, the power of the wave sharply decreases. For reduction of energy consumption, the wave therefore will select an mmWave BS with poor signal quality but without blockage to transmit data. Because the number of macro-cells will affect the communication quality and the computational complexity, this paper especially focuses on three factors of a network: delay, capacity, and path loss, and purposes to figure out the most energy-efficient BS densities for 5G-based green communications.

INDEX TERMS 5G, millimeter wave, delay, capacity, path loss.

I. INTRODUCTION

To enhance and optimize data communications between BSs for 5G networks is the major purpose of this research. Because Massive MIMO is an important technique in 5G, this study makes crucial improvements on access technologies and transmission methods to attain an enhanced access technology with the aid of multiple BSs and small cells. For connectivity optimization, we utilize 5G mmWave because it is highly directional and sensitive to obstacles. Also, mmWave has a narrow beam width which is ideal for small cell usage in the future. How to determine the number of small cells and arrange their positions properly, therefore, is significant for 5G networks [5].

This paper proposes to compute the time difference between the times of arrival of multiple packets in multiple connections and provides corresponding synchronization methods according to the time difference. In addition, we consider different angles between transmitting and receiving antennas and make use of Single-BS precoding with Multi-BS coordination technique for interference reduction between coexisting and newly added BSs. Generally speaking, to guarantee good signal strength and Quality of Services (QoS) in the network, antennas having small angular beam-widths are responsible for transmitting data. Conversely, antennas having large angular beam-widths are responsible for receiving data and detecting the signal strength of adjacent BSs. mmWave occupies a high frequency band that allows it to penetrate thick-wall obstacles but such a feature is not suitable for large scale small cell deployments because of a great deal of power consumption in the process.

The mmWave has high directivity and a small beam width but it is a pity that the interference of atmospheric gases and solid obstacles easily leads to the attenuation of mmWave. Large bandwidth to provide high-quality network services is one of mmWave's benefits. Also, its small angular beam-widths is ideal for largely deployed small cells in 5G networks. Therefore, the number and the locations of small cells must be appropriately arranged. Transmitting (Tx) and receiving (Rx) antennas are different because they are regulated to meet different demands. Small-angle antennas take responsibility for data delivery and thus can ensure network quality and signal strength. Large-angle antennas take responsibility for data reception and thus can search the neighboring BSs and know the quality of their signals. Although mmWave can pass through thick walls due to its high frequency bands, it could consume large amounts of power, which is not good for largely deployed small cells. In our study, we use macrocells to control mmWave BSs and macrocells can choose the BSs that waves can penetrate through thin walls to opposite side for data communications to reach energy efficiency. In the simulation, three major factors, including delay, capacity and path loss, are investigated to find the optimum mmWave BS density. Our study efforts not only enhance the quality of communication, packet synchronization and interference avoidance for 5G networks, but also find an optimum BSs deployment in a target area to attain 5G-based green communications [6], [10], [11].

The rest of this paper is structured as follows. Section II offers an overview of background and related work. Section III describes our proposed scheme that uses mmWave to avoid interference within transmissions. Section IV provides the simulation results and performance analysis. In a specific area with known population and landscape, we want to make a comparison with 4G LTE small cells to find the optimum BS density of mmWave BSs based on delay, capacity and path loss. Section V concludes this paper.

II. BACKGROUND AND RELATED WORKS

A. 5th GENERATION TECHNOLOGY OF MOBILE COMMUNICATION (5G)

International Telecommunication Union (ITU), for Future IMT for 2020, has released a detailed timeline and process that covers 5G key technologies, like Heterogeneous Networks (HetNet) composed of small cell BSs, Massive MIMO, Cloud Radio Access Network (C-RAN), etc. All these technologies are expected to support 10 times higher spectral efficiency, attain 5 times reduced End-to-End (E2E) latency and provide 5Gbps for high mobility users and 50Gbps for low mobility users [1], [8], [9], [12], [15].

METIS (Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society) is currently the largest research project to lay the foundation for 5G mobile and wireless communications. According to the definition of METIS, heterogeneous 5G cellular networks comprise D2D (Direct Device-to-Device), MNs (Moving Networks), UDNs (Ultra-Dense Networks) and URC (Ultra-Reliable Communication), with the attempt to offer multiple interfaces, to reduce traffic pressure on BSs, and to make the 5G networks more flexible. NFV (Network Function Virtualization) and SDN (Software Defined Networking) are considered to be the 5G core networks, both of which are based on the concept of virtualization and therefore save cost on hardware and expand network flexibility. Instead of purchasing new hardware to implement new functions, users can fully control the management system via NFV and SDN and write corresponding APPs for implementation and testing.

B. FINAL STAGE MILLIMETER WAVE (mmWAVE)

Radio waves having the wavelength ranging from 1 to 10 millimeters can travel at the speed of 300,000km/s, approximately the frequency range from 30G∼300GHz. Radio waves having the wavelength ranging from 0.1 to 1 millimeter and in the frequency range between 300G∼3000GHz are called Submillimeter Wave. As for the radio waves in the frequency range between 10G∼30GHz, we call them "microwaves."

Compared with 2.4GHz and 5GHz wireless networks, mmWave has very good directivity, which is highly related to the high frequency bands. When radio waves pass through obstacles, they are attenuated due to the phenomena of reflection and the depth of reflected signals will reduce with the reciprocal of the square root of the frequency. The reflected wave of mmWave is only one fifth of current 2.4 GHz wireless network which proves its good anti-attenuation performance. Thus, mmWave is the best transmission technology between the transmitter and the receiver in an environment without obstacles, i.e. line of-sight communications. In fact, 2.4GHz wireless network can interfere with microwaves, but not mmWaves. To be specific, 60GHz mmWave has approximately 7GHz of bandwidth available in the 60GHz band with a maximum transmit power of 8000 Mw and a maximum raw data rate of 25000Mbits, which obviously outperforms the 600Mbit/s data rate for 802.11n networks.

III. INTERFERENCE REDUCTION BY MILLIMETER WAVE TECHNOLOGY

Supposing many users simultaneously access the same BS or a particular user is occupying most of the bandwidth in a multi-base station environment, the mechanism we present will demand that users occupying most of the bandwidth transfer to uncrowded BSs, or the system allocate traffic loads of crowded BSs to adjacent BSs to keep the communications high speed and high quality in the network.

Assume a user is connected to multiple BSs at the same time and the transmission speed of one of the BSs is decreased due to the large number of obstacles. At this time, the user can switch from the BS with low signal strength to the neighboring BS with better signal strength through a route correction scheme. First, use a BS to perform a scanning for searching mobile stations (MSs) and receive the data returned by MSs, including the number of users, the number of transmitted packets by each user and if the transmission value is within the standard of value [14].

If the transmission value is less than the standard, a message is returned to that MS and the MS determines if the communication is influenced by building blockage, transmission distance, too many users or a particular user who is occupying most of the bandwidth. The result will be returned to the BS as well. If a particular user is occupying most of the bandwidth or too many users access the same BS at the same time, the MS returns related data to the BS and the BS decides whether or not to perform the route correction scheme. When a particular user is occupying most of the bandwidth, the user must be assigned to another BS accessed by fewer users. When too many users access the same BS simultaneously, some of them will be assigned to neighboring BSs. Usually, the data rate remains the same before and after route correction. If not, the BS sends a message to inform the MS near the user and the MS performs a test without affecting users. If a reflected signal from an obstacle is too strong or the transmission distance is too far so that the amount of transmission cannot exceed the original amount, the result is returned to the BS and the BS does nothing. Supposing the amount of transmission exceeds the original amount, a route correction notification will be sent to the MS that requires adjustments [2]–[4].

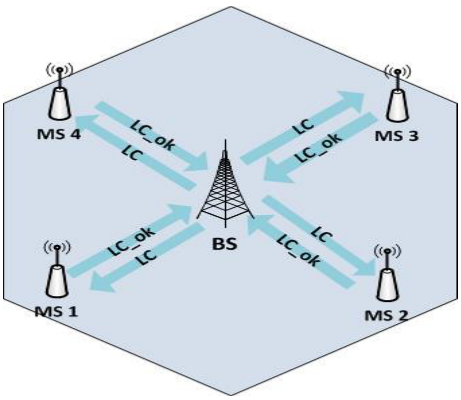

FIGURE 1. Connections over normal routes.

Figure 1 displays the connections between BS and MSs over normal routes. In Equation (1), the BS uses Link Check (LC) messages to confirm its connections with all MSs in its service area. In Equation (2), all MSs verify the connections and return Link OK (L_ok) messages.

$$BS \xrightarrow{LC} MS \tag{1}$$

$$MS \xrightarrow{L\_ok} BS \tag{2}$$

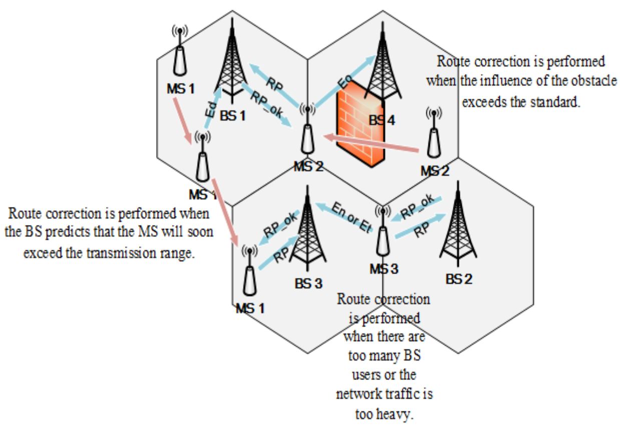

FIGURE 2. Route correction procedure.

Figure 2 displays the abnormal connections between BSs and MSs. If the MSs return one of the following four messages, the BS must transfer users to other MSs: O, D, N and T. O refers to obstacles and the bigger O value means the larger impact of obstacles on signals. D is the distance between users and BSs. N denotes the number of users and T means the required traffic for data transmissions.

D', O′, T′, N′ respectively mean the basal values of distance, obstacle, traffic and number of users. In Equations (3), (4), (5) and (6), MSx means the MS that requires route correction, BSx means the BS that the MS is connected before route correction, BSy means the BS that the MS is connected after route correction and E_o, E_d, E_n, E_t respectively mean the erroneous messages on obstacle, distance, number of users and traffic. In Equation (7), after receiving the erroneous messages, the BSx sends a Replace (RP) message to the MS to ask for route correction. After the MS corrects its route, it sends a Replace OK (RP_ok) message to the BSy to complete the route correction procedure [7].

$$if\, O > O', \quad MS \xrightarrow{Eo} BSx \tag{3}$$

$$if\ D - D' > 0, \quad MS \xrightarrow{Ed} BSx \tag{4}$$

$$if\ N > N', \quad MS \xrightarrow{En} BSx \tag{5}$$

$$if\ T > T', \quad MS \xrightarrow{Et} BSx \tag{6}$$

$$BSx \xrightarrow{RP} MS \tag{7}$$

$$MS \xrightarrow{RP_{ok}} BSy \tag{8}$$

As for the mmWave path loss, we use Equation (9a) to compute the decreased amount of power and please refer to [13] for the detailed introduction of the equation, in which distance plays a significant role. Because the attenuation of mmWave easily occurs due to atmospheric gases and shadow zones, the farther transmission distance will result in the higher signal attenuation. Equation (9) includes these related parameters so that the initial path loss value is higher than 4G LTE networks.

$$PL_{SUI}(d) = PL(d_0) + 10_n \log_{10}(\frac{d}{d_0}) + X_{fc} + X_{RX} + X_\sigma \tag{9}$$

$$PL(d_0) = 20 \log_{10}(\frac{4\pi d_0}{\lambda}) \tag{9a}$$

$$n = a - b \cdot h_{TX} + \frac{c}{h_{TX}} \tag{9b}$$

$$X_{fc} = 6 \cdot \log_{10}(\frac{f_{MHz}}{2000}), \quad f_c > 2GHz \tag{9c}$$

$$X_{RX} = -10.8 \cdot \log_{10}\left(\frac{h_{rx}}{2}\right) \tag{9d}$$

IV. SIMULATION ENVIRONMENT AND RESULT ANALYSIS

The simulation can be divided into two parts: environment setup and data simulation. In the first part, we adopt MATLAB to set up mmWave BSs, arrange randomly or fixed-point distributed walls based on slope, and distribute a large number of users to create a simulation environment. In the second part, we use the mmWave attenuation equation to compute the decreased amount of power in specific environments so as to calculate the time delay and the amount of bandwidth. Based on the three factors, we can find the optimum number of mmWave base stations.

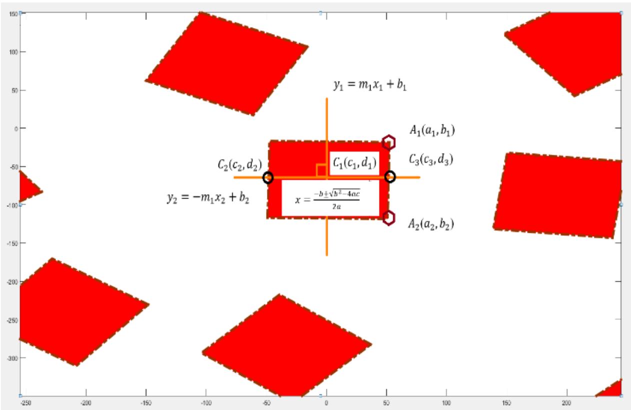

FIGURE 3. Equations and manners to produce randomly distributed walls.

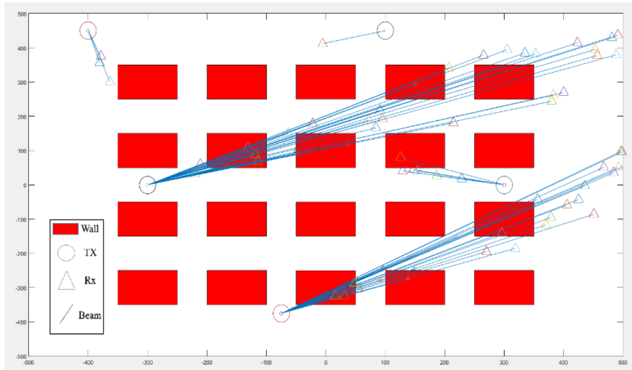

FIGURE 5. The mmWave BSs in the Simulation Environment and the lines connecting receivers and transmitters reveal that they are all in one another's incident and transmitted angle.

A. ENVIRONMENT SETUP

First, to produce blockage "wall" that is essential for the simulation, we adopt the plane coordinate system of MATLAB and produce randomly distributed and size regulable walls according to sine and cosine functions in trigonometry as well as slope, as shown in Figure 3. To build an efficient 5G environment in the future, we can arrange the mmWave BSs based on the surroundings, such as rural areas, cities or parking areas, and specify the size of walls and conditions for distribution. Currently, there is no decided equation to compute the attenuation of mmWaves by blockages. Therefore, in the simulation, a BS without blockages surrounding it will be selected by our proposed scheme for data transmissions. Figure 4 displays how our scheme determines whether there is a way to penetrate a wall. With reference to the slope between the BS and the user, and the intersection points of two unparalleled lines, the scheme can know if there is blockage between the user and the BS and find the penetration distance, which improves simulation accuracy.

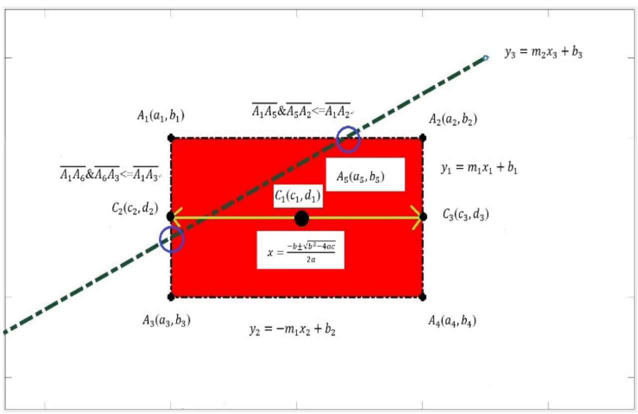

FIGURE 4. The proposed scheme determines whether there is a way to penetrate the wall when the BS transmits mmWaves.

At the beginning, several coordinates of mmWave BSs are generated and the same number of coordinates will be randomly deployed to signify the mmWave directions. To endow receivers and obstacles with directional properties, they will be arranged in the same way. The Figure 5 shows that mmWave BSs in the simulation environment and the lines connecting receivers and transmitters reveal that they are all in one another's incident and transmitted angle. As Equation (10) shows, we use the cosine function to confirm that transmitters and receivers are in one another's transmission range. The creation of obstacles is based on the point-slope form together with the slope of two vertical lines in the linear equation, i.e. -1. Then we use Equation (11) to find the four points of a square and its linear equation. With the linear equation and the truth that two unparalleled lines must intersect each other, our proposed scheme is able to confirm whether there is blockage between the BS and the user.

$$c^2 = a^2 + b^2 - 2ab \cdot \cos(\gamma) \tag{10}$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{11}$$

B. DATA SIMULATION

The purpose of the simulation is to find the optimum number of mmWave BS density in a specific area with known population and landscape and compare the result with 4G LTE small cells in terms of delay, capacity and path loss. We give the simulation parameters in Table 1. In the simulation, mmWave BSs working at a frequency of 28 GHz are endowed with directivity and transmitted angles and we randomly arrange the directional properties of the transmitters. As far as the angle is concerned, we first consider obstructions and large scale small cell deployments and thus choose antennashaving small angular beam widths but high gain for low-level interference and sufficient bandwidth.The receivers, on the contrary, have a high demand for network and must investigate the signal intensity of the adjacent BSs for the most appropriate communication. For such considerations, we choose antennashavinglarge angular beam widths but low gain to be receivers. Obstructions are deployed randomly in the simulation environment. Since the attenuation of mmWave easily occurs due to obstructions, the macrocells will select mmWave BSs with poor signal quality but without blockage

TABLE 1. mmWave and 4G LTE simulation environment.

Frequency Band	28Ghz	1800Mhz
TX height(m)	17	17
RX height(m)	1.5	1.5
TX gain (dBi)	24.5	11
TX HPBW (°)	10.9	45
RX gain (dBi)	13.3	11
RX HPBW (°)	49.4	45
Bandwidth	2Gbit/s~ 10Gbits	200Mbit/s~ 20Mbit/s
Permitted Number of Users	10	10

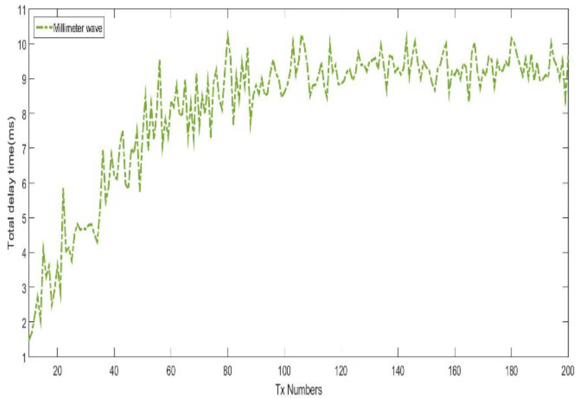

FIGURE 6. Relation between number of mmWave BSs vs. total delay time.

to transmit data for essential quality of connection and energy conservation.

Once a mmWave BS is blocked by obstructions, the system automatically switches to another obstacle-free transmitter. If there is no other choice, the macrocells will be chosen in order to reduce the signal path loss and the power consumption of the BS. There must be some delay while switching from one transmitter to another and the connections therefore must be re-established. To ensure the quality of mmWave transmissions and reduce interference, each BS only permits a specific number of users. The abovementioned delay and number of users are two factors in the simulation. There are 20 walls with a thickness of 10*10m in the simulation and the result is shown in Figure 6. When the number of mmWave BSs ranges between 10 and 50, the total delay time increases quickly maybe because the BSs have narrow coverage initially and users could only connect with the macrocells. When the number of mmWave BSs continues to increase, the coverage becomes much wider. As the number of mmWave BSs comes to 50 to 90, the curve of the total delay time tends to be gentle, the coverage is gradually saturated and users have more BS choices. When the number of mmWave BSs is more than 90, the curve of the total delay time becomes flat and even starts to decline because the number of mmWave BSs increases, the coverage reaches a saturation point and the coverage in the same direction but different distances becomes wider, thus shortening the total delay time and attaining a balance.

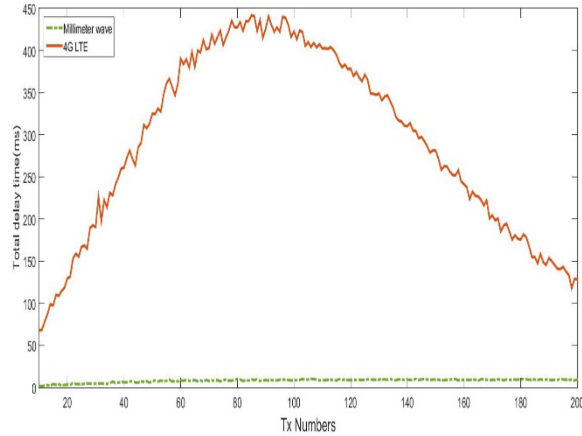

FIGURE 7. Relation between number of mmWave and 4G LTE BSs vs. total delay time.

Figure 7 shows the relation between the number of mmWave and 4G LTE BSs and the total delay time. Generally, LTE BSs provide wider coverage and larger angle. For QoS guarantee, small cells must control the number of users and therefore increases the delay time. In a 1000m×1000m simulation environment with the same number of 30m×30m walls and permitted users, mmWave BSs have shorter delay time because of small angle, small coverage and limited receivers. Although 4G LTE BSs have wider coverage along with the increasing number of BSs, more and more users have exceeded the BSs' capacity, resulting in a sharp increase in the delay time. When the number of LTE BSs reaches 80 or more, the delay time begins to decrease, which suggests the balance between connections and number of BSs. To increase the number of BSs can reduce the delay time but would lead to an increase in deployment cost. Compared with the delay time of mmWave BSs, to attain 20mm or below, there must be more than 200 4G LTE transmitters, which is difficult to control and manage.

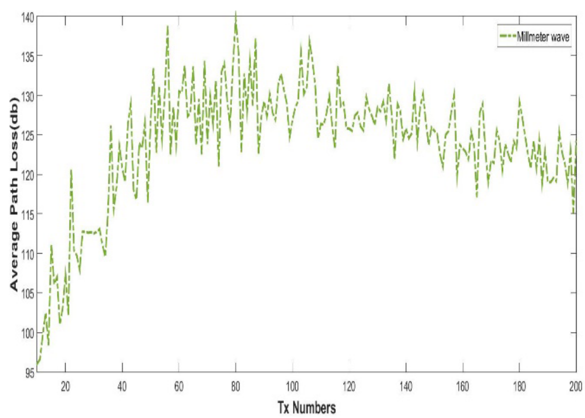

FIGURE 8. Relation between number of mmWave BSs and average path loss.

Figure 8 displays the relation between the number of mmWave BSs and the average path loss and it is interesting that the curve of mmWave path loss is quite similar

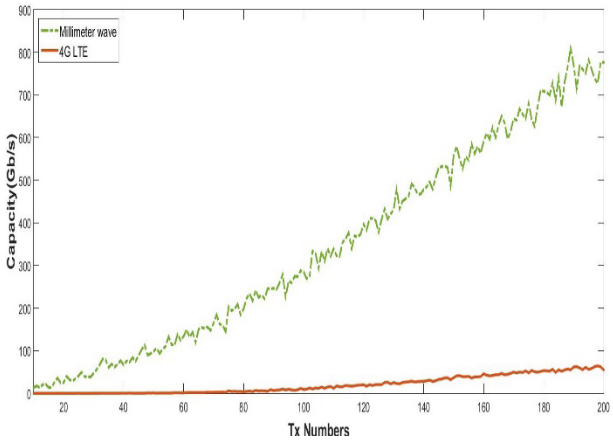

FIGURE 9. Relation between number of mmWave and 4G LTE BSs vs. capacity.

to that of mmWave delay time. The propagation distance and the number of connections deeply affect the path loss. In the initial phase, a BS will find a base station with the shortest communication path. Supposing the communication path is blocked by obstructions, the BS will search for other closest nodes. Because the atmospheric conditions, shadows and obstructions can result in high attenuation of mmWave signals, power and path-loss control is undoubtedly essential in our simulation. As the number of mmWave BSs ranges between 10 and 50, signal attenuation occurs because there are only few mmWave transmitters that can establish connections with few choices of receivers through a long distance. Besides, the walls along the communication path cause severe signal attenuation, resulting in considerable path loss. When the number of mmWave BSs is 50 to 90, the curve of the average path loss tends to be gentle because the mmWave beams now provide wider coverage and the receivers also have a wider choice of transmitters for communications. As the distance between transmitters and receivers is getting shorter, the influence of obstructions gradually diminishes. The curve of the average path loss appears to be flat and even begins to decline as the number of mmWave BSs reaches 90 or more. At this time, not only the network reaches full coverage and more BSs can handle more users, but also the transmission distance becomes shorter and the power consumed will be lower, contributing to energy-efficient 5G-based green communications.

Figure 9 shows the total capacity of mmWave and 4G LTE BSs in a 1000m$\times$1000m simulation environment with 1000 users and the curves both increase with the increase in the number of base stations. Compared with 4G LTE, mmWave BS deployment with lower interference is more suitable for a network in high demand with a large number of users. However, in a low demand network with a small number of users, 4G LTE BSs will be adopted in terms of coverage, power consumption and path loss.

V. CONCLUSION

After going through the simulation, we found that the difficulty lies in the reflection of mmWaves. Attenuation of mmWaves by atmospheric gases and shadows occur because light travels through different materials at different speeds and will refract at different angles. As a wave beam encounters an obstacle, part of the wave beam penetrates but the other part reflects. In fact, users out of beam coverage still can receive mmWave signals because of reflected lights indirectly. Nevertheless, to take packet loss ratio and signal interference into consideration will make the simulation environment more complex. For more accurate simulation results in the future, we attempt to acquire the attenuation coefficients of different media and compute the attenuation of mmWaves when propagating through walls based on the law of conservation of energy: the initial power minus the path loss, the power reduction and the residual power will be the reflected power. Also, the included angle of reflection will be a key factor. With these above-mentioned parameters, we are bound to create a high-reliability simulation environment.

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