

Millimeter-Wave Wireless Backhauling for 5G Small Cells: Scalability of Mesh over Star Topologies

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Abstract—Mobile backhauling, small cells and MmWave are key supportive technologies for 5G revolution. Mobile backhauling is the key enabler and also a showstopper for 5G small cells deployments. Scalability and reliability with high data rate and larger bandwidth are important factors to choose the small cell backhauling topology. In this paper, We consider the star and mesh topologies for the MmWave wireless backhauling. Simulations are conducted over random networks. The system throughput, scalability, reliability and fairness are used to compare the two different topologies under different considered scenarios. These scenarios include the Line-Of-Sight (LoS) and the Non-Line-Of-Sight (NLoS) connections as well as different cell sizes.

I. INTRODUCTION

Mobile is growing into the world biggest technology platform, fundamentally changing the world with each new generation. The 5G enables new services, connects new industries and empowers new experiences. To connect billions of devices, 5G must scales down in cost and power and up in performance to deliver more data rates. 5G must also deliver new level of reliability and latency for mission critical services.

Some of the key technologies that support the revolution to 5G are MmWave, massive MIMO, small cells and backhauling [1]. As much as we have new opportunities using these technologies, there exist many challenges that face their usages. For example, the use of MmWaves suffers from attenuation, free space large propagation, bad penetration and poor indoor propagations [2].

Driven by the demand of more connected devices and better capacity, the number of small cells increases in the network. The increasing density of small cells moves "backhauling" to be one of the main problem facing the deployment of small cells. In [3], a survey over 65 mobile network operator was conducted to show the top 5 barriers for small cell deployment. The survey shows that the backhauling of small cells is one of these top barriers.

Wireless backhauling has been widely considered lately to reduce the infrastructure cost. The wireless backhauling challenges, that need to be consider in small cell deployment topologies [4], are related to the constraints of the used spectrum and the distance. These challenges are addressed using antenna gain, transmitting power and beam-forming. Wireless backhauling also required to be more self-configuring, self-healing, and self-optimizing as the network management become more complicated.

The use of MmWaves links was suggested for small cells backhauling in [5]. In [5], the MmWaves backhauling is suggested in two topologies; the mesh topology and the star topology where the LOS and NLOS links are considered between the small cells of a deterministic layout. In this paper, we study the effect of using MmWaves backhauling in both topologies but we consider a random layout. We also discuss the scalability of the MmWaves backhauling by studying the effect of changing the cell size and the number of small cells on the overall system throughput in both mesh and star cases.

This paper is organized as follows. The system model with star and mesh topologies are discussed in Section II and the simulation environment is explained. In Section III, the simulation results for the star and mesh topologies with different random layout are given. Section IV concludes our paper. Future work is discussed in section V.

II. SYSTEM MODEL

A. Random Layout

The layout represent the geographical distribution of small cells over a given area. In our model, we consider random layouts with 16, 20 and 25 small cells that are randomly distributed over $400 \times 400 m^2$ or $1000 \times 1000 m^2$. Small cells are mounted on the top of the street lamp post. Only one base station, labeled *BS1*, has an FTTC link. All small cells have to route their backhauling traffic to *BS1*. Table I summarizes the system model parameters considered.

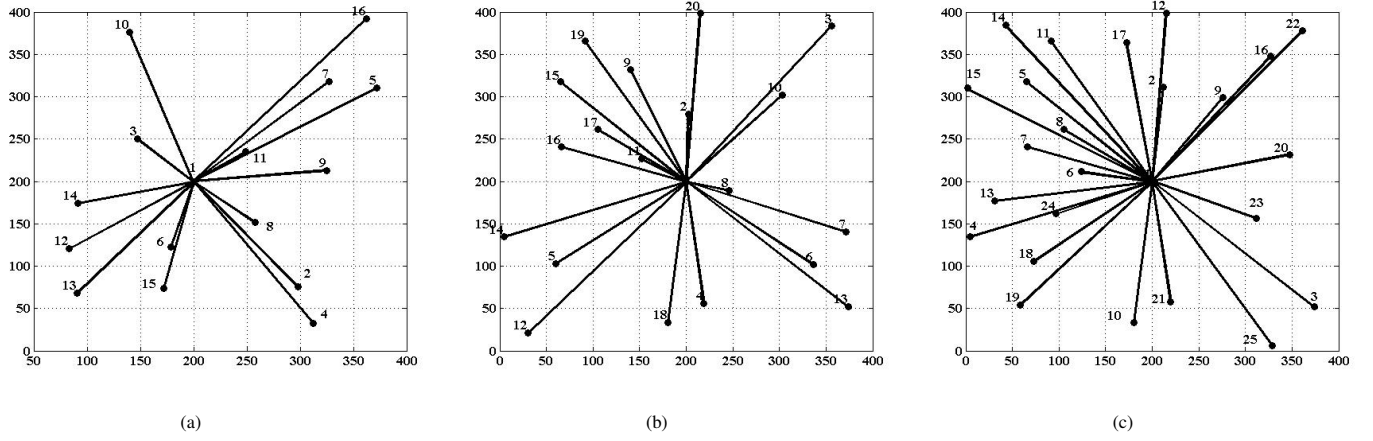


Fig. 1: Random Star Topology for 16, 20 and 25 small cells with area of 400X400.

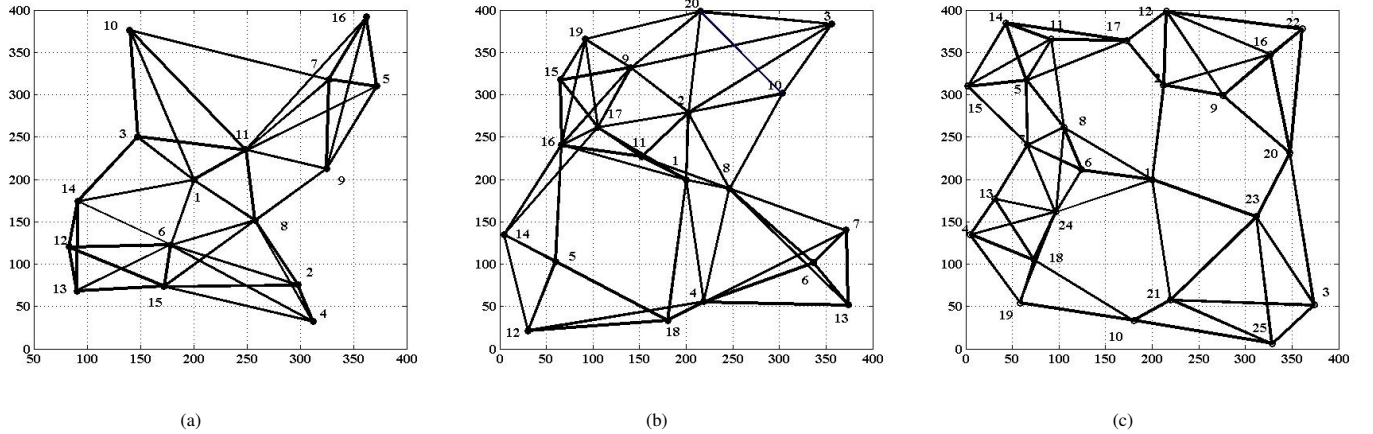


Fig. 2: Random Mesh Topology for 16, 20 and 25 small cells with area of 400X400.

B. Mesh and Star Topologies

Two different topologies are considered for this random layout, the star topology as in figure 1, and the mesh topology as in figure 2. In star topology, the wireless backhaul traffic of small cells is transmitted to the macro cell base station through direct connection between small cells and macro base station and then the aggregated backhaul traffic at the macro cell is forwarded to the core network. Figure 1 represents the random star deployment of 16, 20 and 25 small cells in cell size $400 \times 400 m^2$.

In Mesh Topology, the backhaul traffic of any small cell is relayed by the adjacent small cells to a specified small cell that is connected to the core network. A routing algorithm is

then needed to forward the backhaul traffic between the small cells till reaching the base station. Figure 2 represents sample of random mesh deployment of 16, 20 and 25 small cells in cell size $400 \times 400 m^2$.

C. Mesh Topology Routing

We use Dijkstra algorithm [6] as a routing technique to forward backhauling traffic between different small cells to reach the base station BS_1 ; each node establishes an optimal paths to its nearest neighbors, each link have specific weight or cost determined with a certain KPI. In this paper, we consider the distance or the path cost as the BER of the connection. A good extension for this work is to consider different QOS parameters.

D. Channel Model

The connections between every two small cells may take one of the two types; LOS or NLOS. The path loss used in our simulations is based on a Rayleigh fading channel model for NLOS connections and Rician fading channel model for

TABLE I: System Parameters

Parameters	Description
Small cells height	3-4 meters
Minimum inter-site distance	40 meter
Carrier Frequency	28 GHZ
Modulation technique	16QAM
Bandwidth	20 MHZ

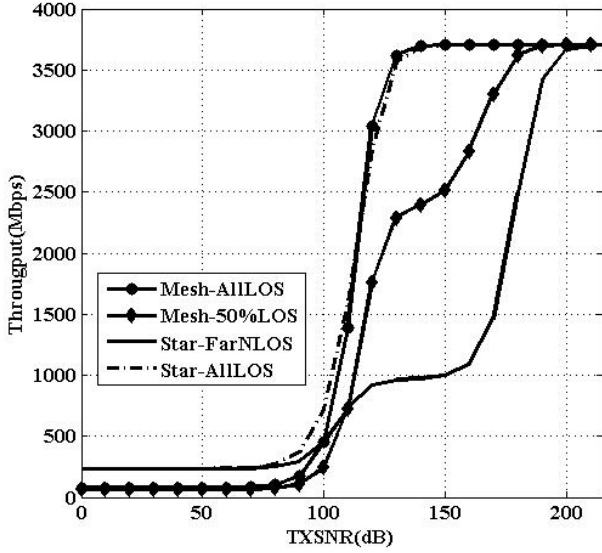


Fig. 3: The total system throughput versus the average transmit SNR per small cell for 20 small cells 400×400 topology area.

LoS connections with 10 taps of multipath channels. The end-to-end multiple hops path BER is calculated as in [7]. We consider working in the 28 GHz band with negligible atmospheric absorption (0.06 dB/km), and negligible rain [8]. The path loss is then given in term of the distance D as in [9], [10], [11], where

$$PL_{LoS} = 61.34 + 20 \log_{10} D, \quad (1)$$

$$PL_{NLoS} = 75.85 + 37.3 \log_{10} D. \quad (2)$$

Jain fairness index [12] is used to measure and compare the fairness of the proposed topologies. For throughput fairness, the fairness here based on the equality of throughput shared from the small cells, so the goal is to have the same throughput from all small cells and the fairness index will be as in 3

$$FairnessIndex = \frac{(\sum X_i)^2}{n \sum X_i^2} \quad (3)$$

Where the normalized throughput X_i

$$X_i = \frac{T_i}{O_i} \quad (4)$$

T_i is the measured throughput and O_i is the optimal throughput measured by any criteria like max-min optimality.

III. SIMULATION RESULTS

We used MATLAB as a simulation tool for channel modeling, topology graphs, bit error rate, throughput calculations and fairness. Simulations were conducted for both area sizes $400 \times 400 m^2$ and $1000 \times 1000 m^2$ in four different scenarios:

- 1) Star topology with 100% are LoS connections (all small cells SC's to BS links are LoS, which is a perfect unrealistic case.)
- 2) Star topology with 50%NLoS, (half of links between SC's and BS are NLoS), where the near connections (closer 5 SC's to BS) are LoS and the far SC's connections are NLoS.
- 3) Mesh topology with 100% are LoS connections (all links in-between SC's and from SC's to BS links are LoS). Connection lengths are chosen randomly with constraint to be larger than 40 meters and less than cell size (400, 1000 meters).
- 4) Mesh topology with 50% are NLoS connections (half of links in-between SC's and between SC's and BS are NLoS), NLoS connections are chosen randomly for every transmission. Connection lengths are chosen randomly with constraint to be larger than 40 meters and less than the cell size.

For star topologies; small cells have direct links to BS, each with a certain path BER calculated. Then system throughput is calculated and plotted against average small cell transmit and average received SNR .

For mesh topologies; small cells have links to their neighboring small cells plus to the BS. Paths BER for all possible connections between small cells and BS are calculated. Then we apply the Dijkstra algorithm that selects the shortest paths between all small cells to the base station $BS1$. Then system throughput is calculated and plotted against the average received SNR and average SC transmit SNR . The generated results are an average of the results of 3 randomly generated cells distribution. Table II summarizes the different cases considered in our simulations.

A. Effect of Different Scenarios

In this section, we fix the number of small cells and the cell size, then we apply our simulation and check the results of different scenarios (100%LoS, 50%NLoS) for star and mesh topologies. Figure 3 shows the difference between the four scenarios with $N = 20$ small cells and the area size of $400 \times 400 m^2$. From the results we can see the advantage of our Mesh with all LoS approach over the Star with Far NLoS one. Mesh with all LoS curves reaches the maximum system throughput of 3700 Mbps with lower level of small cell transmit power than star with far NLoS one. The change in star

TABLE II: Simulation Variables

Area Sizes (A)	400X400 1000X1000
Number of Small Cells (N)	16 20 25
Scenarios (S)	Mesh-All LoS Mesh-50%NLoS Star-All LoS Star-50%NLoS

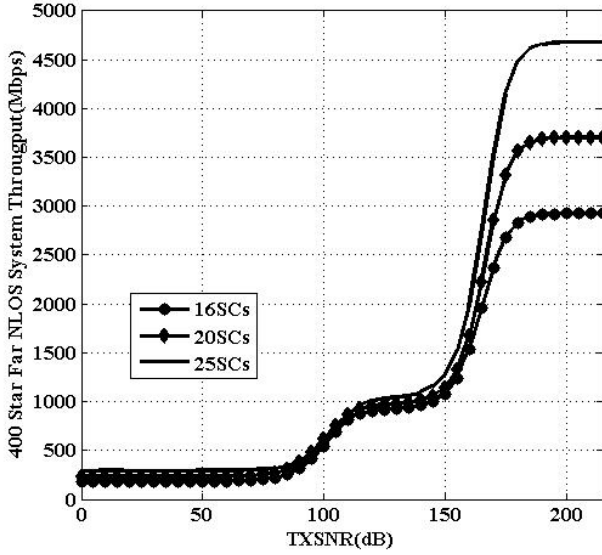


Fig. 4: System throughput versus small cell transmit power for Star with Far NLoS Approach for $400 \times 400 m^2$ area

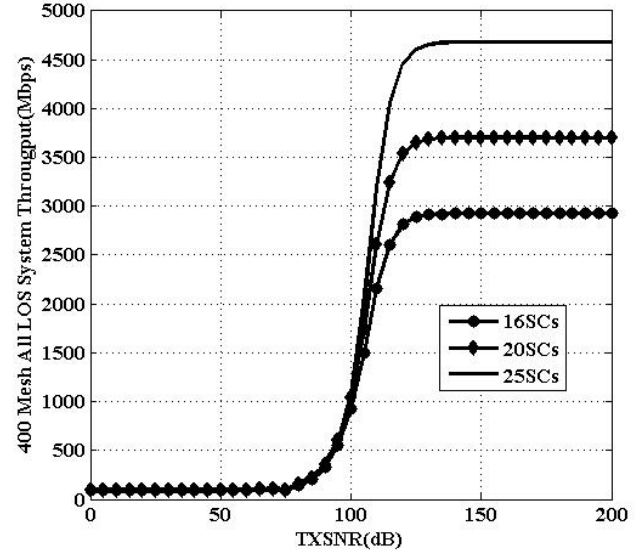


Fig. 5: System throughput versus small cell transmit power for Mesh with All LoS Approach for $400 \times 400 m^2$ area

with Far NLoS curve behavior is due to the NLoS-MmWave path loss effect over the far small cells, so the far small cells require more transmit power to overcome the path loss effect and be able to send their data signals.

B. Effect of Changing Small Cell Numbers

In this section, we fix the cell size and the used scenario. This is mainly required to study the effect of changing the number of small cells. We plot the throughput versus the small cell transmit power for both star with far NLoS case and mesh with all LoS case.

Figures 4 and 5 show the increase in the total throughput when increasing the number of small cell within the same area size for the discussed scenarios. From the figures, it is clear that the case of Star with Far NLoS path is limited when the transmitted power is less than 150 dB as the far links are unable to contribute in the throughput due to limitations imposed by the path loss effect.

The percentage of throughput increase is almost the same among all scenarios; it start from about 2900 Mbps for 16 small cells to 3700 Mbps for 20 small cells then 4700 Mbps for 25 small cells. The percentage of system throughput is almost 25% with the 25% increase of small cell numbers.

C. Effect of Changing Small Cell Sizes

In this section, we fix the number of small cells and used scenarios; this is done to study the effect of changing the area sizes over the same approach and same number of small cells. We then simulate the throughput versus the transmitted power.

Figure 6 shows the effect of changing from cell sizes of 400×400 to $1000 \times 1000 m^2$ areas. The mesh with all LoS approach has a scalability advantages over star with far NLoS one of having degrading of 500 Mbps with 10 dB difference against 1350 Mbps with 20 dB downgrading on Star approach.

The systems without intelligent power transmit power control/limitation may violate the FCC requirements on signal power density. In [7] [8], Theodore S. Rappaport discussed the different criteria for the required transmit power with different types of LoS and NLoS connections and different distances between transmitter and receiver, so we just put a limitation of 120 (dB) as a threshold for the small cell transmission power for both LoS and NLoS connections, considering the path loss effect of MmWave channels. We tested the results over the main two scenarios of mesh with all LoS and star with far NLoS. The Mesh with All LoS approach has achieved a maximum system throughput advantages over the Star with Far NLoS considering that limitation for both topology sizes are as shown in figure 6.

D. Jain Fairness Index Results

In this section, we test the results of fairness index using average system transmit power as a system resource parameter, among all mesh and star scenarios. The 0 value of fairness represents that system is not fair and a value of 1 represents that system is 100% fair in subjected resource allocation among small cells. We use a 20 small cells as an example for showing the system transmit power fairness over cell size of $400 \times 400 m^2$.

Figure 7 shows the Jain fairness index results for all discussed scenarios. Star scenarios achieve 100% fairness of

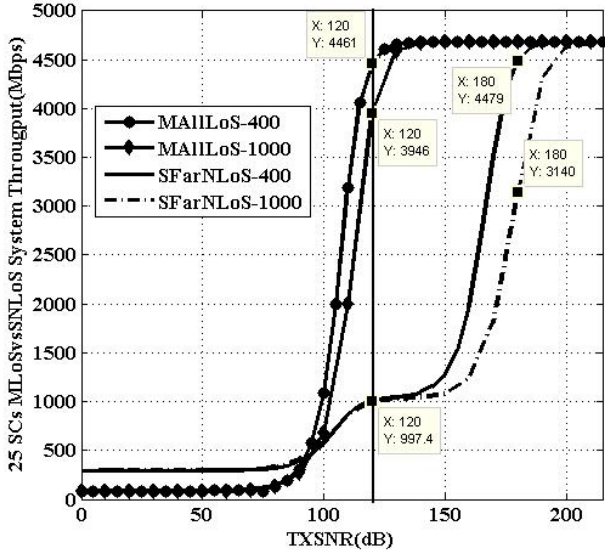


Fig. 6: System throughput versus small cell transmit power for Star far NLoS vs Mesh LoS scenarios for 400X400 and 1000X1000m² area with 25 small cells.

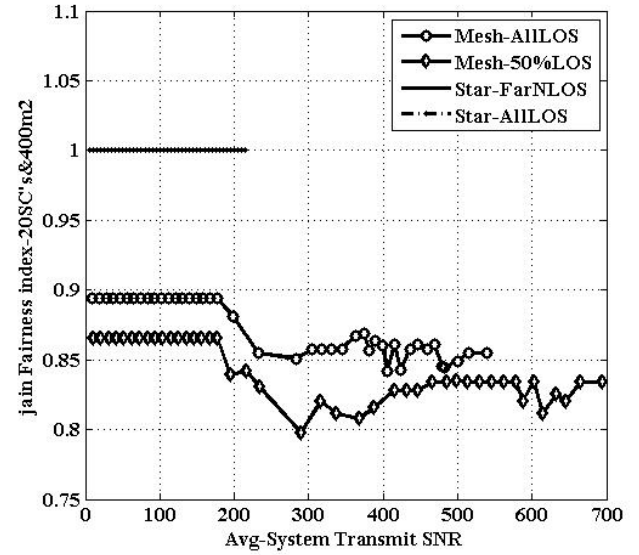


Fig. 7: System average transmit Power vs Jain Fairness index for 20 small cells with 400X400m² area size.

against average system transmit power, it means that system transmit power is equally allocated amount small cells other than mesh scenarios.

In mesh scenarios, the use of routing algorithm makes the small cells not equally share the same transmit power, multi-hop paths create the need for using specific number of small cells to send their signal plus relaying signals for the other small cells, that makes these small cells use more allocated power than other small cells. This creates partially fairness system. Increasing the number of hops lead to decreasing in total system transmit power fairness. So overall system power depends on number of hops participate in relaying other small cells signals to BS.

IV. CONCLUSION

This paper studies the use of MmWave in small cells back-hauling. We test different topologies with different cell sizes and different number of small cells plus different distances between small cell. we proofed the scalability and reliability of mesh approach over the centralized one. we study the effect of transmitting power limitation and throughput and total system power fairness over both scenarios. We suggest the use of the mesh topology as it has a better scalability than the star topology. Simulation results show that the mesh topology can achieve comparable performance to the star topology and might be a good alternative in case the LOS connections are impossible.

V. FUTURE WORK

As of future works on small cell systems with wireless back-hauling, we can apply the former methodology with different

QOS parameter or a combination of certain parameters like total path power transmission with latency and *BER*.

This can give the opportunity to service different classes and priorities for certain network applications like Voice (VoIP), Gaming, Live Video, Buffered Video and TCP Traffic. This leads to consider different key performance indicator KPI's in the backhaul link cost estimation like delay, jitter and latency.

Another extension to this work is Multi-rate System. Using more complex modulation schemes like 64-QAM and 256-QAM; so we can adjust the rate or throughput to specific requirement based on selection criteria.

Massive MIMO is also an extension specially with the use of MmWave; it's motivated by the smaller wavelength feature of MmWave; so with the same antenna aperture, more antennas can be packed into the same area. This helps to reduce the effect of path loss and increase diversity and multiplexing gains. All of this can encourage new technologies as Software Defined Wireless Backhauling, Internet of Thing and Big Data Analysis.

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