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REVIEW OF 5G ENABLING TECHNOLOGIES AND BACKHAULING STRATEGIES

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ABSTRACT

The exponential growth in the demand for data has given birth to the fifth generation (5G) of cellular network. 5G promises massive network capacity, greater bandwidth and negligible latency, which make it very much suitable for 5G requirements like Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low

Introduction

The constant demand for mobile data has resulted in the need for larger network capacity to connect massive number of users which cannot be supported by the previous generation of cellular networks. Fifth Generation (5G), the new generation of cellular network promises to connect enormous amount of users, however, this ground breaking technology must be cost effective and power efficient while delivering greater bandwidth, throughput, reliability, and negligible latency.

To support the increased throughput requirements of 5G, new spectrum has been assigned in millimeter-wave bands to this effect. 5G will use massive Multiple-Input, Multiple-Output (MIMO) to significantly increase network

Latency Communication (uRLLC) and Massive Machine-Type Communication (mMTC). An enabling technique for the realization of 5G network is densification, which sees a lot of small cells deployed in its area of coverage. One way of linking or backhauling these small cells with the core network is through the millimeter-wave spectrum. This is the leading wireless technology for forwarding 5G traffic and especially in urban areas owing to its enormous spectrum availability. Research shows that small cells can be connected in either star or mesh topology for millimeter-wave backhauling, however, this research work will not only review the 5G enabling technologies and compare these topologies, but also propose a topology that prioritizes energy efficiency.

Keywords: 5G, *Backhaul, Millimetre-wave, Small Cells, Topology.*

capacity (Eze et al, 2018). Other enabling technologies include small cells, millimeter-wave (Akyildiz et al., 2016) and mobile backhauling (Nasr & Fahmy, 2017).

This paper reviews 5G enabling technologies, compares millimeter-wave backhauling strategies, and proposes an energy efficient priority topology. It is structured according to the following headings; Enabling Technologies, Topologies of Small Cells, Proposed Topology, and Conclusion. Enabling Technologies reviews the core technologies associated with 5G networks, Topologies of Small Cells highlights the already established topologies with which small cells are laid out, Proposed Topology states a proposal for a topology that prioritizes energy efficiency, Conclusion serves as the concluding part of the paper.

ENABLING TECHNOLOGIES

Massive MIMO

It is an extension of MIMO technology for improving spectral efficiency and throughput (Chataut & Akl, 2020). In massive MIMO, hundreds of antennas are deployed at the base station each with their respective radio frequency chain. This results in massively enhanced spatial multiplexing performance, serving tens of user equipment with greater reliability (Harris et *al.*, 2016).

Increase in the number of antennas in a massive MIMO system result to narrower radiated beams. These beams are spatially focused towards the user. These spatially focused antenna beams increase the throughput for the desired user and reduce the interference to the neighboring user (Chataut & Akl, 2020);

Millimeter-wave

The millimeter-wave spectrum is attractive for future wireless systems because of the massive amount of raw bandwidth that is available for cellular and backhaul services (Alsharif & Nordin, 2016).

According to International Telecommunication Union (ITU), millimeter-wave operates in Extremely High Frequency (EHF) within the range of 30 – 300GHz (Ahmed *et al.*, 2019). The millimeter-wave has the following pros which make it suitable for wireless backhauling of small cells;

Extremely Wide Bandwidths:

Compared with existing wireless networks, millimeter-wave communications employ much higher frequencies as carrier frequencies. Hence, it has much more abundant spectrum resource, making itself quite alluring under the conditions of intensive spectrum (Wang *et al.*, 2018).

Small Element Sizes:

Owing to short wavelengths, mm-wave devices enable large antenna arrays to be packed in small physical dimension (Wang et *al.*, 2018).

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Narrow Beams:

With the same antenna size, it is possible to pack more antenna elements at mm-wave frequencies than at microwave. Therefore, the formed beam can be narrower, which can further facilitate the development of other applications, such as detection radars (Wang *et al.*, 2018).

The propagation properties of millimeter-wave at 60 GHz and at 70–80 GHz are suitable for high network capacity and short range connections. This spectrum is spacious and can potentially minimize interference with highly directive narrow beam-width antennas.

Millimeter-wave signals do not travel very far, and cannot penetrate walls, therefore making small cells vital for their in-building coverage (Oliver, 2021).

Small Cells

One of the major ways through which 5G cellular networks can be enabled is by deploying small cells over conventional macro-cells (Siddique *et al*, 2017). Small Cells are operator-controlled, low-powered radio access antennas. They are low powered devices designed to provide coverage and capacity over smaller areas (Salami *et al.*, 2019). Small cells are majorly categorized into three depending on the coverage area and number of users they can support.

Femtocells:

Femtocells are smallest of the types of small cells. They are designed to provide extended coverage for residential and enterprise applications. The poor signal strength from mobile operators' base stations can be solved using Femtocell implementation. They are primarily introduced to offload network congestion, extend coverage and increase data capacity for indoor users. Femtocells typically support 8 to 16 users with a coverage area of 10 to 50 meters (Baby, 2022).

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Picocells:

Small indoor spaces like buildings or aircraft are covered by picocell cellular base stations. Picocells are utilized to provide more throughput and expanded network coverage. Picocells can be used in businesses, medical facilities, malls, educational institutions, and colleges. (Khan, 2022). Picocells boast a more extensive range of up to 200 meters, they can support a maximum of 100 users (Zola & Lewis, 2022).

Microcells:

Microcells are designed to support larger number of users. Owing to their high transmission power, microcells are capable of covering larger cells sizes. They are suitable for applications like smart cities. The coverage area for microcells is between 500 meters to 2.5 kilometers, supporting up to 200 simultaneous users (Baby, 2022).

The demand for massive network capacity to support more users begs for densification of small cells in the serving area. This moves small cells backhaul to be one of the main problems facing the deployment of smalls cells (Nasr & Fahmy, 2017).

Mobile Backhaul

Backhauling is the forwarding or receiving of the end user traffic to or from the core network, as well as to exchange mutual information among different small cells (Siddique *et al.*, 2015).

There are two methods or ways of implementing backhaul, one way is to use copper or optical fiber in a wired connection, providing high reliability and high data rates (Orainy, 2016). This method of implementing backhaul is very costly and considering the densification of small cells that comes into play for the realization of 5G networks, wired backhauling would also be very complex to implement. In contrast to renting wired backhaul connections from third parties, wireless backhauling has recently been recognized as a practical and affordable

strategy that enables network operators to achieve end-to-end management of their networks. (Siddique *et al.*, 2015).
Some wireless backhaul solutions exist; TV white space, Satellite frequency bands, Sub-6 GHz spectrum, Microwave spectrum, Radio Frequency (RF)/Free Space Optical (FSO), and Millimeter-wave spectrum (Orainy, 2016).
The millimeter-wave spectrum is considered as backhaul solution for small cells, which makes it the most suitable for the backhauling of 5G networks.

TOPOLOGIES OF SMALL CELLS

The millimeter-waves backhauling of small cells is suggested in two topologies; it can either be centralized or distributed (Sahu *et al.*, 2020). The centralized approach is known as the star topology while the distributed approach is known as the mesh topology). In the modeling of these topologies, there is consideration for LOS and NLOS links between the small cells of a deterministic layout (Nasr & Fahmy, 2017).

Centralized or Star Topology

The structure of this topology takes the shape of a star; small cell base stations (SBS) are assumed to be distributed around a single macro cell base station (MBS). All the small cells are configured with equal amount of transmission power, with each having the same coverage (Ahmed *et al.*, 2019). The traffic of each SBS is forwarded to the MBS only through the single link established between the SBS and the MBS. The aggregate of all backhaul traffics sent to the MBS is forwarded through fiber-to-the-cell (FTTC) link to the core network (Nasr & Fahmy, 2016).
The star topology has a simple structure and therefore easier to implement and maintain. Since all SBS directly connects to the MBS, there is a single point of failure for each SBS. The structural representation of the star topology of small cells is presented in Figure 1.

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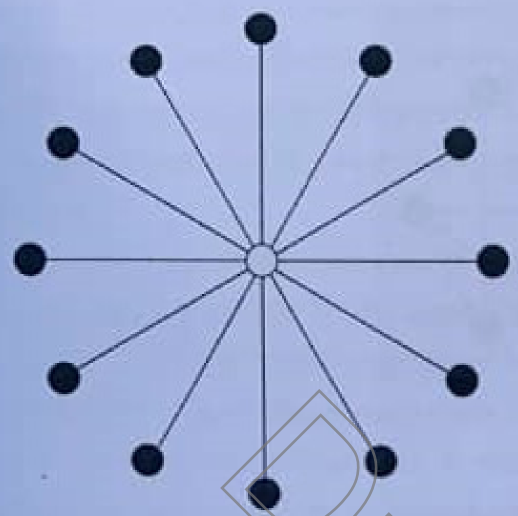

Figure 1: Layout of the Star Topology distributed or Mesh Topology

In this topology, there is no centralized MBS, however, all small cells, distributed over a given area, forwards their backhaul traffic to adjacent small cells that relay the backhaul traffics to the dedicated or specialized small cell acting as the aggregator. This small cell connects to the core network via the FTTC link, through which the aggregated backhaul traffics is forwarded to the core network (Nasr & Fahmy, 2016).

The mesh topology has a more complex structure, making it harder to implement and maintain when compared with the star topology, however the superiority of the mesh topology over the star topology has been well established by Nasr & Fahmy (2017) and Ahmed *et al.* (2019). SBS in this topology have more than one way to connect to the aggregator node, eliminating the problem of single point of failure. The structural representation of the mesh topology of small cells is presented in Figure 2

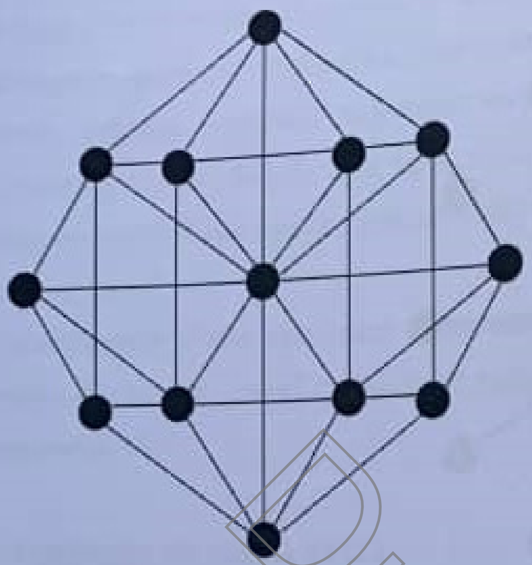

Figure 2: Layout of the Mesh Topology

Nasr & Fahmy (2017) used Dijkstra algorithm, a routing technique for computing the shortest path to a network node according to some key performance index (KPI) to forward backhaul traffic from the SBS to the aggregator node using Bit Error Rate (BER) as KPI.

PROPOSED TOPOLOGY

Nasr & Fahmy (2017) and Ahmed et al. (2019) stated that efficient wireless backhauling of small cells is a fundamental challenge. A survey of over 65 mobile network operator was conducted to show the top five (5) barriers for small cells deployment. The survey shows that the backhauling of small cells is one of these top barriers (Nasr & Fahmy, 2017). The limitation of the backhauling strategies for small cells configuration can be such as, the connectivity between dense small cells deployed in the serving area, how to optimize the throughput of the uplink, downlink, and the overall system of all the small cells and the energy consumption of the system and how to optimize the energy dissipated in the system (Ahmed et al., 2019).

Nasr & Fahmy (2017) stated that in mesh topology of millimeter-wave wireless backhauling of small cells, some of the small cells' backhaul

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traffics go through multi-hop paths, they also relay signals for the other small cells, this makes them use more transmit power. Therefore overall system power depends on number of hops participating in relaying other small cells signals to the base station. It is on this note that we propose a topology that aims to conserve energy through very limited multi-hop routing.

In this topology, a node connects to the central or aggregator node and to its adjacent nodes – no more. These adjacent nodes are also connected directly to the aggregator node and each to their adjacent nodes. With this structure, each node has three path to the aggregator node through which they can forward their backhaul traffics. The structural representation of the proposed topology of small cells is presented in Figure 3.

Figure 3: Layout of the Proposed Topology

The topology is designed to offer path flexibility thereby eliminating single point of failure and reducing link congestion. With the availability of multiple path to the aggregator node for any SBS, Dijkstra algorithm is employed to route backhaul traffic using suitable Quality of Service (QoS) parameter as KPI. Since energy conservation is the outmost priority is this system, the system is designed to forward backhaul traffic via multi-hop only when it absolutely has to, that is only if the algorithm considers that path as the shortest path.

A setup like this is proposed to be more energy-efficient than the traditional mesh topology while also addressing the issue of link congestion associated with the star topology.

CONCLUSION

This paper reviews the enabling technologies of 5G, its backhauling strategies and also proposes a strategy that aims to conserve energy by reducing the overall transmit power of the system. Wireless backhauling is preferred to wired method because of the complexity associated with wired backhauling especially with the densification of small cells base stations. The millimeter-wave is also preferred amongst the wireless backhaul solutions as it is well applicable for the implementation of small cells. Research shows the superiority of mesh topology over star topology – mesh topology primarily offer multiple path to the aggregator node, thereby greatly reducing link congestion, but we have also proposed a topology that could reduce link congestion while conserving more system energy.

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