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Energy-Efficient Design with Wireless Backhaul In 5G Mm Wave Using Cellular Networks

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A B S T R A C T

The volume of global mobile data traffic is expected to increase exponentially in the coming years. To enable this, disruptive solutions are required for 5th generation mobile networks (5G). Network capacity can be increased by enhancing spectral efficiency, cell density, as well as by procuring new spectrum. Considering the expected demand, all three will be essential. Millimeter wavelength (millimeter-wave) (30 GHz and above) spectrum was always known to be ample and underutilized, but was previously not considered favorable for mobile communications due to its radio propagation properties.While millimeter-waves offer more bandwidth than all of the spectrum below 6 GHz combined, they require a substantially different approach. A particular issue is the maximum length of a millimeter wave mobile access link; cell radii are estimated to be at most only hundreds of meters due to the unfavorable link budget. Millimeter waves will enable very dense cell layouts for extremely high network capacities.

Introduction

The volume of global mobile data traffic is expected to increase exponentially in the coming years. To enable this, disruptive solutions are required for 5th generation mobile networks (5G).

Millimeter wavelength (millimeter-wave) (30 GHz and above) spectrum was always known to be ample and underutilized, but was previously not considered favorable for mobile communications due to its radio propagation properties.

While millimeter-waves offer more bandwidth than all of the spectrum below 6 GHz combined, they require a substantially different approach. A particular issue is the maximum length of a millimeter wave mobile access link; cell radii are estimated to be at most only hundreds of meters due to the unfavorable link budget. Millimeter waves will enable very dense cell layouts for extremely high network capacities. The backhaul for small cells is seen as the biggest challenge for small cell deployments. As the number of cell sites multiply to keep with capacity demand, so increment in the cost of the operator's backhaul network. While fiber is widely used for macro- cell backhaul, many operators are suggesting that the high cost of fiber installation and leasing fees will kill the small cell business case. Instead, operators are estimating that 80% of the small cells will be connected with wireless backhaul. This leads to the technological challenge of finding wireless solutions that provide enough spectrum in a cost effective manner, and that can sustain the expected continued growth in capacity. This paper will also reveals hidden advantages and shortcomings of backhaul solutions, which are not evident when backhaul technologies are inspected as an independent part of the 5G network.

Along with the advantages of 5G architecture, there also come several major technical challenges. The massive deployment of small cells poses potential challenges in network management, including interference alignment, extensive backhauling, and inconsistent security mechanisms over heterogeneous networks. Network management and service provisioning are challenging in this multi-tier model due to the increased number of base stations and complexity of the network architecture. Therefore, new technologies are needed to provide intelligent control over mobile networks for consistent and effective resource allocation as well as security management.

Moreover, 5G users may leave one cell and join another more frequently with reduced cell size, which could introduce excessive handover-induced latency in 5G. Future 5G applications like interactive gaming and tele-operations require low latency.

There are some common issues present in the Mobile Networks field:

- Throughput of the channel: a characteristic influenced by the transmission channel bitrate and the amount of protocol and error-correction coding overhead incurred by the transmission system.

- However, due to smaller cell deployment, users and different access points (APs) in 5G need to perform more frequent mutual authentications than in 4G to prevent impersonation.
- The mobile traffic in the uplink and downlink can be highly asymmetric. The ratio of downlink to uplink traffic varies in the range of 4:1 to 8:1. The backhaul resource allocation solutions should be able to exploit this traffic asymmetry to utilize the backhaul resources efficiently.

LITERATURE REVIEW

According to U. Siddique, H. Tabassum, E. Hossain, and D. I. Kim [1], the primary challenges of wireless backhauling of small cells in a multi-tier cellular network have been focused on, where several types of backhaul solutions can coexist. Different wireless backhauling options have been compared qualitatively. At this, a two-tier 'macro-small cell network has characterized the backhaul-limited regions where the downlink transmission capacity of a small cell user is constrained by the transmission capacity of a half-duplex system. Correspondingly, the system access link and the backhaul link operate in different timeslots.

In "5G Ultra-Dense Cellular Networks" [2], a distributed network architecture with single and multiple gateways are presented for 5G ultra-dense cellular networks. Considering the millimeter-wave communication technology, the impact of small cell BS density on the backhaul network capacity and energy efficiency of ultra-dense cellular networks is investigated. Simulation results indicate that there is a density threshold of small cells in ultra-dense cellular networks.

According to Z. Pi, J. Choi, and R. Heath [3], they proposed a millimeter-wave gigabit broadband (MGB) system for both fixed access and backhaul evolution toward 5G. Due to its distinctive ability to provide wide-area gigabit-per-second coverage, the MGB system is flexible, scalable, and cost-effective as the last-mile solution for gigabit-per-second fixed broadband and as the small cell backhaul solution for gigabit-per-second mobile broadband. In an exemplary MGB system with 500 MHz bandwidth at the 39 GHz band, the simulation shows that a single MGB hub with 3 sectors can guarantee 1 Gb/s peak rate and 100 Mb/s average throughput to 96 small cells within a 1 km radius with 99 percent probability.

In the "Survey of Resource Management Toward 5G Radio Access Networks" [4], has discussed a number of (radio interference and resource management) RIRM schemes towards the evolution of 5G RAN (radio access network) systems. While previous surveys have had a narrow focus on particular issues related to 5G communications, e.g., green communication or interference management, etc., this current survey has provided a much broader but a fairly in-depth perspective. They have pointed out some pressing issues and challenges of radio resource management under macro headings of interference management, spectrum efficiency, energy efficiency, and hybrid resource management. As the 5G RAN systems promise increasing traffic demand with diversified QoS (quality of service) performance requirements, there has been a real need for researchers to devise optimal RIRM strategies. As a result, the current review paper has presented some challenges, solutions, and open research issues of the RIRM strategies proposed towards achieving the identified visions of the 5G RAN systems to date.

According to H. Tabassum, A. H. Sakr, and E. Hossain [5], the performance of a massive MIMO-enabled wireless backhaul network has investigated, which is composed of a mixture of small cells configured either in the in-band or out-of-band FD (full-duplex) backhaul mode. The feature of massive MIMO at CNs (cellular networks) and shared-antenna-based full-duplexing at SBSs (small cell base stations) can enable the use of the proposed framework in existing LTE-A standards. Downlink coverage probability has been derived for a typical user considering both the In-Band Full-Duplex (IBFD) and Out-of-Band Full-Duplex (OBFD) modes. It has been shown that selecting a correct proportion of out-of-band small cells in the network and appropriate SI (self-interference) cancellation value is crucial in obtaining a high-rate coverage. Few remedial solutions for backhaul interference management have been presented. The framework can be extended to include multiple antennas at SBSs to consider the possibility of serving users through CNs, i.e., depending on the coverage requirements a user can opportunistically switch between SBSs and CNs. Further extensions to this work could include the effect of opportunistic scheduling on the rate coverage probability.

According to H.H. Yang, G. Geraci, and T.Q.S. Quek [6], they undertook an analytical study for the energy-efficient design of heterogeneous networks with a wireless backhaul. In addition, they used a general model that accounts for uplink and downlink transmissions, spatial multiplexing, and resource allocation between radio access links and backhaul. Results revealed that, irrespective of the deployment strategy, it is critical to control the network load in order to maintain a high energy efficiency. Moreover, a two-tier heterogeneous network with wireless backhaul can achieve significant energy efficiency gain over a one-tier deployment, as long as the bandwidth division between radio access links and wireless backhaul is optimally designed. The framework provided in this paper allows explicitly characterizing the power consumption of the Het Net due to the signal processing operations in macrocells, small cells, and wireless backhaul, as well as the data rates and ultimately the energy efficiency of the whole network.

According to Q. Han, B. Yang, G. Miao, C. Chen, X. Wang, and X. Guan [7], given a Het Net powered by hybrid energy, which focuses on the backhaul-aware joint user association and resource allocation problem. To balance network-wide performance and user fairness, then formulate an online network utility maximization problem reflecting PF (proportional fairness), which has tightly coupled variables (both binary and continuous) in the constraints of resources, energy, and backhaul. Then, by adopting some decomposition methods, the condition for two kinds of resource partition of a BS is efficiently obtained, and a completely distributed algorithm is developed. Finally, the convergence of the distributed algorithm is proved by employing results of the subgradient method. In a wireless backhaul system, the traffic of several adjacent small cells is usually routed to a backhaul hub or gateway, which has fiber connections to the core network.

According to Y. Niu et al., "Energy-Efficient Scheduling for mmWave Backhauling of Small Cells in Heterogeneous Cellular Networks" [8], they do not consider the routing strategies in the problem. In future work, they will jointly optimize the routing strategy, the concurrent transmission scheduling, and power control to achieve an energy-efficient wireless backhaul system. Extensive simulations demonstrate our scheme achieves the lowest energy consumption and highest energy efficiency compared with other two schemes. Under heavy load, our scheme improves the energy efficiency by about 64.8% compared with the TDMA scheme. By investigating the performance of our scheme with different interference thresholds, they show the threshold should be selected elaborately under different traffic loads, BS distributions, and the maximum transmission power to achieve low energy consumption and high energy efficiency.

In "Centralized and Distributed Energy Efficiency Designs in Wireless Backhaul HetNets" [9], they focus on the joint design of transmit beamforming and power allocation that maximizes the AEE (access energy efficiency) on the DL (downlink) of the two-tier wireless backhaul small cell HetNets. An important impact of decoding power at each SAP (small cell access points) that is proportional to the achievable backhaul rate at each small cell is considered. In the first centralized algorithm, a global optimal solution has achieved through a very high complexity algorithm based on BnB (branch-and-bound) approach. In the second centralized algorithm, a much lower complexity algorithm based on FOTCA (first-order Taylor convex approximation) which helps in achieving a local optimal solution by iteratively solving the convex approximated problem of the non-convex problem.

According to M. Jaber, M. A. Imran, R. Tafazolli, and A. Tukmanov [10], they have proposed an energy-efficiency-aware implementation of the user-centric backhaul concept. The scheme uses a two-step optimization approach: the first is centralized and the second is distributed. The centralized step strives to reduce the number of active last-mile links while respecting the user-defined quality-related constraints. The distributed step optimizes the settings of the broadcast quality-related bias factors of all cells in the system according to the ON/OFF status of their last-mile links.

According to G. Wang, G. Feng, S. Qin, and R. Wen [11], they have proposed a traffic engineering framework that optimizes the maximum link utilization of SDN-based 5G core and backhaul networks by jointly considering the DGW (data gateway) selection problem. Firstly, they have formulated the IFDA-TE (Inter-DGW Flow Distribution and Traffic Engineering) problem as a multi-commodity problem. To solve this problem with close-optimality performance and high scalability, they proposed an improved algorithm of FPTAS (fully polynomial time approximation scheme) (i-FPTAS). With the proposed DGW selection strategy (i.e., MBODA and MFODA), that can alleviate the cooperation signaling load between DGWs and mobile network controller.

According to R. A. Pitaval, O. Tirkkonen, R. Wichman, K. Pajukoski, E. Lahetkangas, and E. Tiirola [12], in-band backhauling for 5G small cell networks has been proposed. A flexible frame format enables effective use of time and frequency resources for uplink, downlink, and backhaul transmissions. Relay nodes are densely deployed in the network to provide routing diversity for two-hop transmissions. A two-hop (full-duplex) FD self-backhauling flow has two possible bottlenecks, either self-interference in the FD relay or interference from the direct transmission to the destination. The dominant bottleneck depends on the link distances and the efficiency of self-interference cancellation at the FD relay. Coordinated RRM (radio resource management) between the self-backhauling and access hops proves to be efficient. The drawback of the discussed solution is increased infrastructure costs due to the numerous relay nodes.

Research Gap:

Extensive research surveys have been carried out, showing that mobile networking will be a challenging task for 5G technology. Networks that use heterogeneous backhaul solutions, composed of fiber links, 'xDSL,' mm-Wave, and sub-6GHz, and derive the mean packet delay over both the radio and backhaul networks. Given that energy consumption has leading importance in future networks, recent works have addressed modeling this backhaul aspect based on carried traffic. The key challenges are outdoor propagation impairments of mm-Wave signals, multi-hopping in microwave and mm-Wave bands, backhaul delay, non-uniform user traffic, etc.

Objective of the Proposed Research Work:

The goal of our work is to encounter the challenges present in the backhaul technique for the fifth-generation cellular network.

- We will propose a resource allocation technique in wireless backhaul mesh network.
- We will provide a solution for backhaul resource allocation to develop adaptively control in traffic load conditions in the small cells.
- Minimizing the delay due to packetization and processing in the uplink and downlink.
- Improvement in the performance of an end-to-end network with mmWave access links, including latency.

- Increasing the throughput in terms of both average and stability.

Methodology Of the Proposed Research

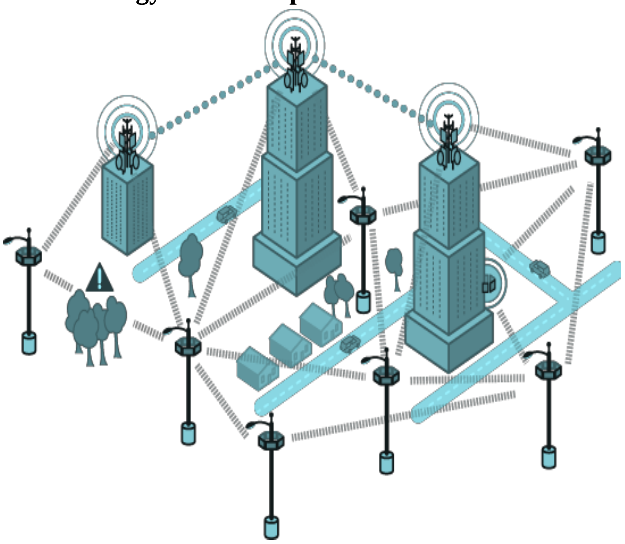

Figure 4.1: mm-H multi-hop directional mesh small-cell backhaul

The mm-wave multi-hop directional mesh small-cell backhaul is a crucial component of the fifth-generation (5G) cellular network. It aims to achieve maximum throughput and minimal latency for the mesh network. To accomplish this, a fully scheduled, synchronized, and time-division duplex (TDD) based multi-hop directional mesh medium access control (MAC) protocol is developed.

The use of electrically steerable antenna arrays enables fast TDD operation, reducing the need for multiple baseband and RF processing chains for each individual link. Operating at mm-wave frequencies provides some immunity against interference. Additionally, automatic interference management techniques are employed to overcome any overlapping directional beams and external interference.

Expected Outcome:

The proposed model is expected to provide an efficient backhaul technique for the 5G cellular network, with the following outcomes:

- Energy efficiency tradeoffs will be optimized to ensure savings at base stations (BSs) and small cell access points (SAPs) are not counteracted by increased consumption at user equipment (UEs), and vice versa.
- Problem identification to maximize the total system throughput while minimizing the unsatisfactory performance perceived by served users.
- The proposed end-to-end network technique will help reduce latency in the mobile network.

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