Challenges and Research Advancement in 5G Wireless Backhaul Networks

Haseeb Malik\(^1\), Humaira Afzal\(^2\), M. Rafiq Mufti\(^3\), Asghar Ali\(^4\), Ali Hassan\(^5\)

\(^1,2\)Bahauddin Zakariya University, Multan, Pakistan
\(^3\)COMSATS University Islamabad (Vehari Campus), Pakistan
\(^4,5\)National College for Business Administration & Economics, Lahore (Multan Campus), Pakistan

Corresponding author: humairaafzal@bzu.edu.pk

Abstract

5G networks should achieve Gigabit speed in the future cellular network. Getting higher speed is a considerable challenge to manage the 5G Wireless Backhaul Network functionally. This research studies two network wireless backhaul architectures such as small cell networks and millimeter-wave transmission technologies for Centralized and Distributed scenarios. In addition, for various network topologies and wireless backhaul network frequency bands, energy efficiency is compared. Numeric comparative findings give guidance for deploying inexpensive and high energy capability of future 5G wireless backhaul networks.

Keywords: Networks, Wireless, Cell, Traffic, Energy, Distributed, Central, Efficiency

Introduction

To solve the issues of increasing wireless communications traffic (say 2020 compared to 2010 level) in the next decade, more research is expected in cellular networks of the next generation (5G networks). Furthermore, several prospective transmission technologies are emerging that helps in increasing the volume of wireless communication thousands of times in the future. In the same frequency bandwidth, the Massive Multiple Input and Output (MIMO) transmitter technique is verified to enhance the efficiency of spectrum to 10-20 times. The technology for Millimeter-wave communication is being researched for
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cellular systems with frequency bands more than over 100MHz. The millimeter-wave and massive MIMO technologies will decrease cellular communication coverage noticeably. Networks of small cells are therefore established in 5G communication. In this scenario, 5G networks are basically up gradation of previous networks, by adding more spectrum and, hence, it increases capacity, or substitutes modern radio technology. It requires to reconsider the physical layer from the system and architectural layers. In addition, we must answer how hundreds of ultra-dense traffic may be forwarded to network backhaul with guaranteed quality of services (QoS) and sustainable systems for economical consumption of energy. In recent years, cellular data traffic is continuously growing; the Gigabit-level data traffic cannot be satisfied economically and ecologically in the existing cell system architecture. The small cell system is one solution, heavily used by small base stations with small cell base stations (SBSs) with low power. In initial research, the interference to signal and noise ratio (SINR) for wireless connections around restricted hot zones is improved by the modest number of cells integrated into conventional mobile networks. In this case, traditional backhaul links between cell networks may be transferred to the main network from small cells if small cells are distributed very intensively in cellular networks. The transfer of enormous backhaul traffic to the primary network is a significant challenge.

Moreover, the concerned issue is that, because of the frequent transfer and mobility resilience, the vast number of small cells signals cause the network nodes to rise when the transmission fails. Simulation at the system stage has examined LTE-Advanced systems for small cell deployments to perform mobility. The results of the simulation indicated that the transfer optimization methodology might reduce effectively, the failed handover rate. With fast-growing microwave point-to-point technology, wireless solution backhaul has become a stunning choice for networks with small cells. Simulation-based experimental results show that, the high-frequency technology of the microwave was a promising high-level performance option in wireless backhaul for small cell lines in the case of non-line-of-sight transmission (NLOS). In addition, the NLOS backhaul high-level performance employing more frequencies beyond sub-5 GHz may be available to deliver the more significant antenna gain used for the same sizes of antenna. It is feasible to create small and compact, fixed backhaul point-to-point lines at a speed of hundreds of gigabits. In the last kilometer high-capacity and pre-aggregation backhaul, 60, 70 and 80 GHz mm-wave communication systems were explored. In addition, the topic was investigated as an optical technology supplement to provide a flexible and cost-effective hybrid coverage for the availability of OFDM technology for passive optical networks. Using network modeling, requirement results of small urban cell backhaul applications, Mobile hybrid backhaul networks, millimeter/optical waves with flexible, high-capacity data, revealed a very prospective future backhaul mobile networks option.
The coordinated multiple points (CoMP) technique is employed in small cells for reducing interference between sites along with improved efficiency of the spectrum. Furthermore, traffic in backhaul is created by the possible method of exchanging data among cooperating small cells. The required bandwidth for the backhaul coordinating systems. On the other side, a small cell network's energy efficiency is of tremendous significance since the base station (BS) density would be greatly enhanced. Energy efficiency of small cell network was basically based on the random space network model. Numerical experiments demonstrate that small cell network's energy efficiency is efficient power consumption model that is dependent on the BS. In contrast to other 5G-network research, 5G wireless backhaul networks can achieve performance and energy efficiency in Ultra-dense, compact, and communication of the millimeter-wave. For comparison analysis, we first set up two typical scenarios for small cells in detail. Then, we explore models based on two common small cell scenarios for the wireless backhaul with different spectrum efficiency. In addition, 5G wireless backhaul networks that have energy efficiency in two frequent cases is studied using numerical findings. Moreover, several wireless backhaul frequency ranges connecting 5G backhaul networks to energy efficiency are explored for two common situations. Finally, future issues of 5G networks is of exploring wireless backhaul and then conclusions are formed.

System Model

Figure 1: The centralized Scenario of 5G wireless backhaul networks: (a) Physical Architecture of Centralized scenario, (b) Logical architecture of centralized scenario
With immense communication MIMO and millimeter wave technology, the future 5G networks, small cells are an inevitable way to solve the problem of providing fast communication. This paper presents a scenario consisting of two small cells that are provided for the evaluation the 5G wireless backhaul network’s throughput and energy efficiency. Fig 1 (a) shoes the first backhaul solution. A microcell Base Station (BS) is supposed to be discovered in the microcell center, the distribution small cell Base Station (SBSs) in the microcell is considered uniform. All SBSs have been configured with similar service and coverage transmission. Fig. 1 shows that small cells of wireless backhaul communicate through microwave to MBS transmission links, then traffic backhaul aggregate at MBS is then transferred to cell links via fiber to the Cell (FTTC) connections. Two logical interfaces X1 and X2 are used in the central solution to forward backhaul traffic. X1 is the feeder for advance gateway user data to the MBS, and it is the virtual network gateway that provides advance access. X2 allows for exchange of mutual information between small cells. The Fig. 1(a) illustrates the detailed scenario and logical architecture of central wireless backhaul network and so as Fig. 1 (b). Fig. 2 shows the second solution for backhaul as the distribution solution. There is no small cell MBS for collecting entire backhaul traffic. Compared to the central solutions in Fig. 1, all the traffic is backhaul referenced in a specified SBS. Every SBS is supposed to be distributed homogenously in a particular region in Fig. 2. The whole traffic in one SBS is transmitted via nearby SBSs through wave communications of thousands of meters. All SBS adjacent transmissions are transferred to a defined SBS linked to the leading network in cooperation with fiber optic to the Cell (FTTC) connections. In the central solution and distribution solution, the X1 and X2 functions equally. Fig. 2(a) and Fig. 2(b) illustrate detailed scenarios and logical architecture of distributed wireless backhaul network.

**Backhaul Traffic Models**

While there are several traffic types for small cell systems, in which much more traffic is caused by user generated data, but, on the X1 interface, the protocol of transmission and backhaul transfer between nearby small cells produce significant components of traffic in backhaul transport. In addition, wireless administration besides synchronization traffic is neglected. This article shows that, this traffic is not as much of in small cell networks than other networks. Here it is supposed that small cells or the specified SBS (Small cell base station) are ideally interconnected with the wireless Backhaul. Data traffic generated by users is linked to the bandwidth and with the frequency efficiency of small cells. In broader view, every small cell is supposed to have similar efficiency of the bandwidth and spectrum. In such undergoing situation, the backhaul stream of the small cell as production will be clarified.
Figure 2: 5G Wireless Backhaul Network Distribution Solution: (a) Physical Architecture of Distribution Scenario, (b) Logical Architecture of Distribution Solution

Results show that traffic is 10% of backhaul overhead on S1, while 4% is expected to be produced on small cell network interfaces X2 is assumed to be generated.

Central Solutions for Backhaul Traffic Model

For backward traffic generation, the primary solution contains the small and macro cells for uplink and downlink traffic. The rate of uplink traffic for small cell is described as

\[ TH = 0.04B \cdot S, \]

where B is a small cell bandwidth and S is the small cell average speed efficiency. A small cell is estimated by downlink performance for which

\[ TH = (1 + 0.1 + 0.04)B. \]

transmitted via S1 backhaul network interface. The macro cell uplink performance is described as

\[ TH = 0.04B, \]

of macro cell and S is macrocell average efficiency. The macro cell downlink rate is determined by

\[ TH = (1 + 0.1 + 0.04)B. \]

backhaul network interface S1. Suppose that the traffic in each small cell is balanced. A macro cell configures N as total number of small cells. The entire rear-link performance
of the center solution is computed as $TH = N \cdot TH + TH$ and overall downlink backhaul performance is determined as the central solution by $TH = N \cdot TH + N \cdot TH$. As a result, the overall central solution backhaul rate is summarized as $TH$.

**Distribution Solutions for Backhaul Traffic Model**

The nearby small cells transmit the traffic to a backhaul chosen i.e. SBS in the distribution solution. Therefore, in nearby cooperative SBSs (Small cell base station), the channel is shared among data users. Without the loss of generally, adjacent clusters of small cells are organized cooperatively, and are taken as $K$. Deprived of the defined SBS that gathers whole traffic commencing from nearby small cells, the cooperative clusters efficiency of spectrum is indicated as $S$, where $S$ is the small cell $(k - 1)$ spectrum efficiency of the cooperative clusters. Given the overhead cooperation in the cluster for cooperatives, a small cell cooperative's uplink backhaul output is described as $TH = 1.14 \cdot B$, where $B$ is the small cell bandwidth. A small cell backhaul cooperative downlink is indicated as $TH = 1.14 \cdot B$. S. The overall backhaul rate as a solution for distribution scenario is summarized as $TH = K \cdot (TH + TH)$.

**5G Wireless Backhaul Networks Energy Efficiency**

The cellular network energy consumption should contain operational energy along with embedded energy. This paper presents that the operational energy is being defined as $= \text{where}$ is BS power and operational capacity, is the lifetime of the BS. The linear function of transmission power of the BS has no generality loss assumed to operate the BS and which is expressed as $= a +$. The energy of transmission is often dependent on the coverage radius and propagation of decreased signal.

**Table 1: Wireless Backhaul Networks Parameters**

| Wireless backhauls frequencies | 6 GHz | 30 GHz | 58 GHz |
|-------------------------------|-------|--------|--------|
| (radius of coverage 550m)     | 22.50 | 22.50  | 22.50  |
| (radius of coverage is        | 351.33W | 351.33W | 351.33W |
|                               | 10 W  | 233 W  | 1070 W |
|                               | 568 W | 5352 W | 23305 W |
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| 550m)       | 75 GJ | 75 GJ | 75 GJ |
|-------------|-------|-------|-------|
| $E_{\text{init}}$ | 10 GJ | 10 GJ | 10 GJ |
| $E_{\text{Minit}}$ | 12 years | 12 years | 12 years |
| $E_{\text{Minit}}$ | 7.56 | 7.56 | 7.56 |
| (coverage radius is 60m) | 70.48W | 70.48W | 70.48W |
| (coverage radius is 60m) | 6.3mW | 147mW | 675mW |
| (Total power consumption percentage) | 71W | 72W | 76W |
| + | 25% | 25% | 25% |
| + | 6 years | 6 years | 6 years |

The transmission power of The MBS is standardized as Watt (W) to facilitate a model derivation with coverage range kilometer (Km). Similarly, the radius coverage power of the BS transmission is described as............../a, where a is coefficient of path loss coefficient. Additionally, the BS radius is r and operating power is represented as/a. The BS encompasses energy, which is calculated as $E = P + P_{\text{ini}} + E_{\text{m}}$. In the main solution, energy consumption of the system is expressed by

$$E = K_a + K_b + N$$ (1)

$$= + + + + + +$$

Considering the wireless backhaul output in the centralized solution, the energy efficiency is given as $E / K_a$.

The energy consumption of the system is expressed by

$$E = K_a$$ (2)

In view of the wireless backhaul output of distribution solution, the distribution solution energy efficiency is defined as $E / K_a$.

The default settings are defined as follows to evaluate the power of 5G wireless network efficiency in two backhaul options. The small cell radius is 60 meters and that of macro
cell is 550 m, bandwidth of the macro cell is 100 Mbps, and the macro cell average range efficiency is 6 bits/s/Hz. For the urban context, the path loss coefficient is 3. The power of BS parameters are synchronized as $a = 22.50$, $b = 351.33$ accordingly in macro cell as W. BS operational power settings are adjusted as $a = 7.56$ and $b = 70.48$ W, both. MBS and SBS have 6 and 12 years of life, respectively. The lifetime is expected. Table 1 lists other factors.

![Diagram](image)

(a)

![Diagram](image)

(b)

**Figure 3:** Control of the number of small cells with various average wireless backhaul network spectrum efficiency: a) Centralized scenario, b) Distributed Scenario

First, the number of small cells is considered for comparisons of different mean spectrum efficiencies for the performance of wireless backhaul networks in Fig. 3. In Fig. 3(a), with the increase in the smaller core cell numbers solution, the traffic backhaul grows linearly. In Fig. 3(b), from the expansion in the quantity of small cell distribution solution, there is much increase in throughput. The backhaul flow increases exponentially. The growing characteristic of the distribution solution results from the sharing of cooperative traffic between small cells. The backhaul performance increases with the growth small cell average efficiency of the spectrum when small cells number is unchanged.
Second, the wireless backhauls network energy efficiency concerning a lot of small cells, including the frequency bands is distinct, and is shown in Fig. 4(a), wireless backhaul network energy efficiency is increasing with the central logarithm solution of small cells. With the growth in the amount of small cells in the distribution solution, wireless backhaul network energy efficiency grows linearly. Wireless backhaul network's energy efficiency decreases when an increase reduces the small cells in frequency bands. However, the immediate solution has gaps in energy efficiency at 6GHz, 30GHz, and 58GHz.

![Figure 4: Energy efficiency with relation toward the number of small cells with various frequency bands in wireless backhaul networks: a) Centralized Solution, b) Distributed Solution](image)

Lastly, Fig. 5(b) shows energy performance of the backhaul wireless networks concerning the path loss coefficient given various small cell radii. If the radii of small cells are not as much of 60 meters or equal to 60 meters, wireless networks enhance their energy efficiency by increasing the path loss coefficient. If the radii of smaller cells are greater than 60m, wireless energy efficient backhaul systems will decrease as the coefficient of loss of paths increases. This is because the increase of track loss coefficients. Based on the Shannon theory, it has a small attenuating influence on the wireless capacity if the radii of smaller cells are less than or equal to 60m. The increasing
path loss coefficients, by contrast, definitely have a wireless ability to mitigate effect when a small cell radius is greater than 60m. Wireless backhaul networks energy efficiency in the energy system is proportional to wireless power consumption and is fixed. Compared to central solutions given in Fig. 5, in distribution solution, the main solution energy efficiency is less than the distributed solution energy efficiency within the same small cell range and the path loss coefficient.

Figure 5: Wireless backhaul networks are energy efficient for the track loss coefficient taking into consideration various small radii of cells: a) Centralized Scenario, b) Distributed Scenario

Future Challenges
In the current studies, to fulfill the high-capacity requirements for cell network in hot areas, the small cell network is presented. The massive wireless traffic in limited hot zones is therefore only sent. In this situation, the traditional cell network architecture allows a small traffic to backhaul to be brought back directly to the main network. The cell size for 5G networks must be reduced with massive MIMO communication technologies and millimeter-wave, being included in 5G networks. In addition, the overall wireless traffic of 5G networks is transmitted.

Moreover, a 5G network is becoming a high-density small cell network. As a result, the other 5G wireless backhaul networks will face a massive problem in low-cost
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and high-energy efficiency massive wireless traffic into core networks. In the following context, several potential issues are presented.

The first challenge is how to design ultra-dense cell deployment scenarios with new network architecture and protocols. As discussed in the last paragraph, the main features for future 5G networks are ultra-dense deployment and small cells. In this situation, the unit area increases the efficiency of small cells. Therefore, the respective traffic of backhauls exponentially increases on the gateway, if the usual central control concept is used in the structural design of the 5G backhaul network. Not only does enormous backhaul traffic congestion, but the backhaul network also collapses. In the 5G backhaul network architecture, the distributed model of control must be implemented. However, it comes with it whether current network protocols are another challenge that sustain massive traffic through the Wifi links.

The second problem is how the handover effect in small cells may be mitigated for high-speed users. The concept of a small group of cooperatives will facilitate high-speed users to transfer data between small cells to solve this challenge. In this scenario, several small cells have to cooperate with a high-rate user to transfer traffic. Whenever the high-speed user leaves from the small cell, the small cooperative cells other than this take cover the track and forward traffic to the high-speed user sequentially. Furthermore, the new small cell, also based on the high-speed user track, has been introduced to the cooperative small cell group. However, several problems need to be resolved to achieve this concept, like building a dynamic, collaborative cells groups and make a strategy to reduce the overall sharing of data of the small cells in the cooperative. Even with a specified QoS, it is critical that the enormous wireless backhaul traffic may be reverted to the leading network, deploying it in exceedingly energy efficient way. Specific research has shown that low power consumption BS is reduced in 5G networks by densely deployment. But based on our analytical conclusions, different backhaul network topologies have various models of energy efficiency. For example, the central solution, for instance, reaches a limit when a small cell density is more significant than the threshold. For future 5G networks, it is essential to enhance the wireless backhaul network energy efficiency. There are potential solutions to the energy efficiency issue, hybrid backhaul networks, for example, integrating wireless and fiber cables. In addition, the new small cell sleeping model and adaptive capacity management for SBSs provide efficient energy savings approaches in 5G wireless backhaul networks. However, shortly, further research is expected.

In 5G wireless backhaul networks, to resolve these problems, solutions are summarized as:

1. The architecture and protocols of distribution cells may explore wireless transmission over extremely dense small cell networks.
2. Massive traffic in backhaul wireless 5G networks are proposed for millimeter wave communication.
3. In order to resolve handover problems in small cell networks, cooperation with small cell groups should be studied.
4. To assure the low energy consumption deployment of 5G wireless backhaul networks, high power technologies should be developed for efficient transmission.

**Conclusion**

5G networks will meet the rapid expansion of wireless traffic. Transmission rate in Gigabits using 5G networks, massive MIMO, millimeter-wave distribution/communication, and small cells concepts and technologies are presented here. In this paper, we are looking at promoting high-performance and low energy 5G networks of wireless backhaul. The analysis of future 5G wireless backhaul networks is performed using two usual small cell scenarios. Moreover, energy efficiency is evaluated with two common small cell situations of the wireless backhaul networks. Numerical results indicate that in 5G wireless backhaul networks, distribution approach has more incredible fundamental solution in terms of energy efficiency.

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**References**

Bhushan, N., Li, J., Malladi, D., Gilmore, R., Brenner, D., Damnjanovic, A., ... & Geirhofer, S. (2014). Network densification: the dominant theme for wireless evolution into 5G. IEEE Communications Magazine, 52(2), 82-89.

Bojic, D., Sasaki, E., Cvijetic, N., Wang, T., Kuno, J., Lessmann, J., ... & Nakamura, S. (2013). Advanced wireless and optical technologies for small-cell mobile backhaul with dynamic software-defined management. IEEE Communications Magazine, 51(9), 86-93.

Chen, M., Mao, S., & Liu, Y. (2014). Big data: A survey. Mobile networks and applications, 19(2), 171-209.

Coldrey, M., Berg, J. E., Manholm, L., Larsson, C., & Hansryd, J. (2013). Non-line-of-sight small cell backhauling using microwave technology. IEEE Communications Magazine, 51(9), 78-84.

Hoydis, J., Kobayashi, M., & Debbah, M. (2011). Green small-cell networks. IEEE Vehicular Technology Magazine, 6(1), 37-43.

Humar, I., Ge, X., Xiang, L., Jo, M., Chen, M., & Zhang, J. (2011). Rethinking energy efficiency models of cellular networks with embodied energy. IEEE network, 25(2), 40-49.
Jafari, A. H., López-Pérez, D., Song, H., Claussen, H., Ho, L., & Zhang, J. (2015). Small cell backhaul: challenges and prospective solutions. EURASIP Journal on Wireless Communications and Networking, 2015(1), 1-18.

Jungnickel, V., Manolakis, K., Jaeckel, S., Lossow, M., Farkas, P., Schlosser, M., & Braun, V. (2013, June). Backhaul requirements for inter-site cooperation in heterogeneous LTE-Advanced networks. In 2013 IEEE International Conference on Communications Workshops (ICC) (pp. 905-910). IEEE.

Khirallah, C., Thompson, J. S., & Rashvand, H. (2011). Energy and cost impacts of relay and femtocell deployments in long-term-evolution advanced. IET communications, 5(18), 2617-2628.

Li, C., Zhang, J., & Letaief, K. B. (2013, June). Energy efficiency analysis of small cell networks. In 2013 IEEE international conference on communications (ICC) (pp. 4404-4408). IEEE.

Misra, S., Chatterjee, S. S., & Guizani, M. (2015). Stochastic learning automata-based channel selection in cognitive radio/dynamic spectrum access for WiMAX networks. International Journal of Communication Systems, 28(5), 801-817.

Robson, J. (2011). Guidelines for LTE Backhaul Traffic Estimation. NGMN White Paper, 1-18.

Samardzija, D., & Huang, H. (2009, August). Determining backhaul bandwidth requirements for network MIMO. In 2009 17th European Signal Processing Conference (pp. 1494-1498). IEEE.

Taleb, T. (2014). Toward carrier cloud: Potential, challenges, and solutions. IEEE Wireless Communications, 21(3), 80-91.

Yamamoto, T., & Konishi, S. (2013, September). Impact of small cell deployments on mobility performance in LTE-Advanced systems. In 2013 IEEE 24th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC Workshops) (pp. 189-193). IEEE.