Green Backhauling Solutions for 5G HetNets

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Abstract**—** With the rapid growth and evolution of information and communication technology, energy consumption is also growing at a very fast rate. The amount of carbon dioxide ( ) emissions from the cellular networks will be 345 million tons by 2020. A major 5G research challenge is to achieve up to 90% energy savings. To address the challenge of drastic power demand, researchers have focused on "Green Communications and Networking" to develop energy-efficient solutions for next generation wireless communication standards. This paper analysed an energy efficient communication model for 5G Heterogeneous Networks (HetNets) and proposed an energy saving model using MATLAB. Simulated results revealed that the proposed green communication model saves 38% of power than other existing models.

Key Terms**—** *Energy efficiency, Green Communications, Heterogeneous Networks, Traffic Backhauling, 5G.*

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I. INTRODUCTION

The 4G wireless communication system is not equipped to meet the explosive growth in traffic demand. That is why researchers are heading towards a new generation called 5G which is expected to provide 1000x more capacity, than the 4G networks. This technological advancement demands a rise in transmit powers.This would result in a rise in the greenhouse gas (GHG) emissions. The projected carbon footprint until 2020[1], of the mobile communications is illustrated in Fig. 1.

Large energy consumption has a direct impact on the emissions into the environment. The telecommunicationsector greatly contributes to increased emissions, with its share being about2%, at present. In spite of being a minute percentage, it is extremely substantialas this is expected to increase drastically in near future. It is thus necessary for the5G cellular networks to take into account minimization of the energy consumption. Only 15% of the energy is used for the network operation, with the rest 85% not contributing at all to generating the revenue. Clearly, the energy efficiency of the networks needs to be enhanced, for greener next generation networks.

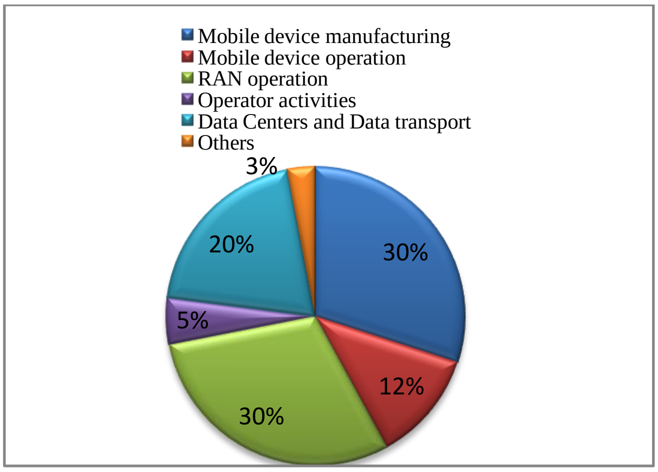

Fig. 1. Carbon Footprint of mobile communication (projected in 2020)

Ecological and economic implications of the global emissions pay a way for 'Green Communication'. Energy-efficient wireless communication is imperative, looking into the whereabouts of the present-day scenario.

II.GREEN COMMUNICATION MODEL FOR 5G HetNets WITH BACKHAULING SOLUTIONS

HetNet is a mixed wireless infrastructure, with a combination of fewerhigh power macrocells and many low power small cells (e.g., micro, pico, andfemto), that brings the network closer to the end user, thereby offering higher signal-to interference-plus-noise ratio (SINR), which in turn improves link robustness and quality of service (QoS). In a HetNet, high reuse of frequency can greatlyreduce the bandwidth scarcity problem. Another major 5G research challenge isto achieve up to 90% energy savings.

Both access and backhaul network power consumption contributes to total power consumption in 5G HetNet systems. While SCNs help to reduce thebandwidth scarcity problem in HetNet, increasing numbers of uncoordinated andlightly loaded active SCNs can increase the access network power consumption. Fig. 2 shows the networkarchitecture of a 5G HetNet, where an access network is comprised of a macrocelland several SCNs.

A backhaul networkiscreated by connecting the base stations to the core network through variousbackhauling solutions including wired, wireless or mixed architecture of existingtechnologies.

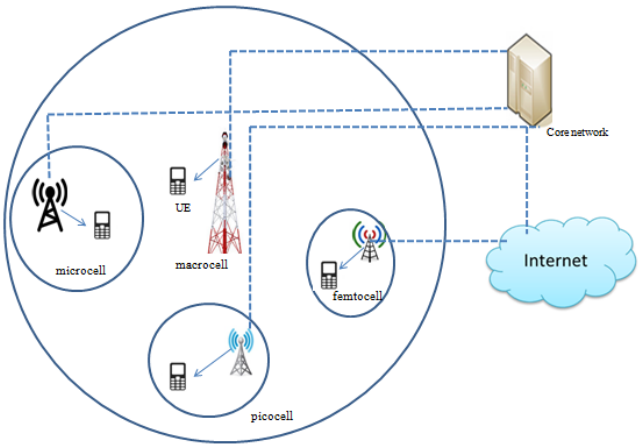

Fig.2. Network Architecture of a 5G HetNet

A. Fiber optic point to point Ethernet solution

The Ethernet/IP interface is frequently used in the third

Generation Partnership Project (3GPP) to backhaul traffic. In this design, the Ethernet switch canbe used in a centralized or de-centralized manner for the aggregation node. Trafficgenerated from all wireless base stations (MBS or SCN) is collected at one aggregation switch, which then forwards data to the core network as shown in Fig. 3a.In this solution, all backhaul links (i.e., base station to aggregation switchand aggregation switch to core network) are optical fiber. An optical small-formfactor pluggable (SFP) interface is used to connect the port of the Ethernet switch.

Therefore, the backhaul power consumption for this solution is given by[2]:

$= [\ (+\ )] + (\ + +$ (1)

Where denotes the maximum number of downlink interfaces available at the aggregation switch for collecting the backhaul traffic of a HetNet. represents the total number of active SCNs for a particular hour of a day. is the number of the macro base station of the HetNet. The power consumption of a switch has two main parts:

$= \alpha\ + (1- \alpha)$ (2)

The first part models the back-plane of the switch, which is traffic independent. The other depends on the aggregated backhaul traffic that passes through the switch . The weighting parameter α Є [0,1] is assumed for balancing the relative influence of power quantities. is the maximum amount of traffic that a switch can handle, while represents the maximum power consumption of a switch. and denote the power consumption by one downlink and uplink interface in the aggregation switch, respectively.Total aggregated traffic collected at the switch is represented as: = + , where and denote the MBS and SCN aggregated traffic, respectively. = is the total number of uplink interfaces, denotes the maximum transmission rate of an interface.

B. Fiber to the building and 10Gbps passive optical network solution

This solution consists of a fiber to the building (FTTB) scheme with GPON(gigabit passive optical network) technology as presented in Fig.3b. The wireless backhaul traffic iscarried to the core network through passive optical networkarchitecture. The SCNs are connected to a GES (gigabit Ethernet switch) by fast Ethernet (FE) links.

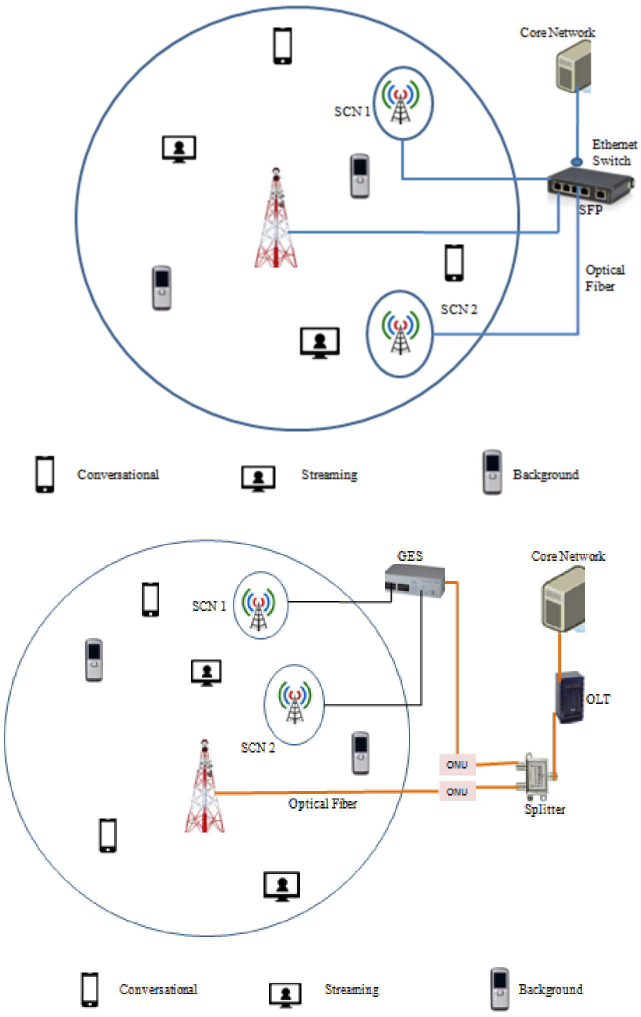

Fig. 3. Existing Backhauling Solutions a) Fiber Optic Point to Point Ethernet solution, b) Fiber to the building and 10Gbps passive optical network solution

GES traffic is sent to the optical network unit (ONU) via a gigabit Ethernet (GE) port. The MBS is connected to an ONU through a 1 Gbps optical fiber link. Traffic from all ONUs is aggregated to optical line terminal (OLT) via passive splitters, which are in turn connected to the core network. In the uplink, each ONU shares 2.5 Gbps bandwidth and in the downlink, OLT broadcasts 10 Gbps to the ONUs. Therefore, the backhaul power consumption for this solutioncan be computed as[3][4]:

= (+)+ + + (3)

Where , , and correspond to the power consumption of GES,ONU, OLT port and SFP+ module, respectively. = is the number of required GES-ONU, while is the port number of GES. In this design, the number of OLT interfacesis calculated as, = [ ], where is the number of passivesplitters.

For the final section, the number of uplink interfaces for this design can becalculated as, =). For the optical P2P Ethernet solution, the Ethernet switch consumes a maximum amount of power (300 W) depends on traffic load.For the FTTB + 10 GPON solution, the power hungrycomponent is the gigabit Ethernet Switch PGES (50 W). These analyses demonstrate that high backhaul power

consumption is caused by several components which motivate us to design two new energy-efficient solutions.The following twosubsections will describe these solutions.

C. Energy efficient passive optical network solution

In this design, each SCN is connected to an optical network unit (ONU) via an optical fiber link shown in Fig.4a. ONUs are connected to an OLT through passive splitters. We consider rack/shelf OLT model for 10 GPON technology, where an OLT is fully equipped with maximum configuration, implementing layer-2 aggregation functionality. Each OLT has a shelf rack, 9 line cards, SFP+ arrays, and 72 GPON ports (2.5 Gbps/port). To guarantee a 100 Mbps data rate for each ONU (SCN) units, the maximum number of ONUs (SCNs) supported by one GPON port can be calculated as: = 2:5Gbps/100Mbps = 25ONU(SCN). The aggregated traffic from ONUs to OLT is sent to the core network by using a 10 Gbps optical fiber link and SFP+ modules. Therefore, the backhaul power consumption for this proposed model can be obtained as[5]

= (+) + + (4)

Where and represent active SCN number and macro base station numbers at a particular hour during a day. is the power consumption ofeach GPON port and is the power consumption of an ONU. In this proposeddesign, the number of GPON ports in an OLT is calculated as, =[ ]. is similar to that of previous case.

Fig.4. Energy Efficient Backhauling Solutions a) PON solution b) mmWave solution

A. Energy efficient millimeter wave solution

In this solution, we use the unlicensed 60 GHz frequency band for the mmWavetechnology in order to connect SCNs to the MBS as illustrated in Fig. 4b.The point-to-point line of sight (LOS)mmWave backhaul links are denoted bya set

M= where each mmWave backhaul link k isrepresented by a set of that includes all SCNs which backhaul their trafficthrough it, ie; j Є .

A MBS is connected to the optical network unit which in turns sends traffic to the optical line terminal. SFP+ modules and a 10 Gbps optical fiberlink are used to carry the aggregated traffic to the core network. Therefore, all SCN traffic is backhauled bymmWave and the rest of the traffic is carried byPON. The backhaul power consumption for this proposed solution can be calculated as[5]:

=)+ + + (5)

Where is the load dependent radio frequency transmit power consumption for any link. The link can be from an SCN to an SCN aggregation nodeor an SCN aggregation node to an MBS. denotes the fixed power consumption by each backhaul link. , and represent the power consumptionof an OLT port, an ONU and SFP+ modules, respectively. In this proposed solution, the number of GPON ports in an OLT can be calculated as, = [ ]. Lastly, for transmitting the aggregated traffic from the MBS to the core networkthe number of uplink interfaces can be computed as, =). Effective isotropic radiated power (EIRP) of 60 GHz mmWave band islimited to maximum 40 dBm. In addition, we consider an adaptive modulation andcoding technique (AMC) to maintain a minimum achievable SINR for successfully transmitting the aggregated traffic through a backhaul link. The minimum SINRcan be written as[6]:

Where denotes the bandwidth and is the aggregated capacity generatedfrom all SCNs of the link k. Due to high path loss at 60 GHz, generated interferenceis negligible, i.e., SINR = SNR. Therefore, the radio frequency transmission powercan be written as[7]:

= - - + + + + + + + (7)

Where and represent the transmission and receiving antenna gain,respectively. = 20log10( ) dB is the tolerable path loss, while wavelength = 5x m is for 60 GHz and d is the length of each BH link. = 20log10( ) dB is the path loss at 1 meter distance. We consider implementation loss , shadowing loss , and attenuation loss for this design. It is assumed that 16 dB/kmattenuation occurs due to oxygen absorption in the atmosphere and 18dB/km attenuation for the 50 mm/h rainfall, which ensures 99.995% availability. For each backhaul link bandwidth , the thermal noise =10log10( ) - 174(dBm), and the noise figure NF (dB) are estimated.

IV. RESULTS AND DISCUSSION

We evaluated the system performance through simulationsin MATLAB. In this paper, we consider the temporal and spatial fluctuation characteristics of network traffic. Fig. 5 shows a typical temporal hour-by-hour distribution of normalized peak traffic loads[16], which captures three types of traffic information (i.e., conversational, streaming, and background), over one week with a resolution of one second in a suburban area. Conversational traffic (high priority) such as voice and video conferencing is highly delay sensitive. Streaming traffic (medium priority), such as streaming audio and video, has relatively less delay sensitivity than conversational traffic.

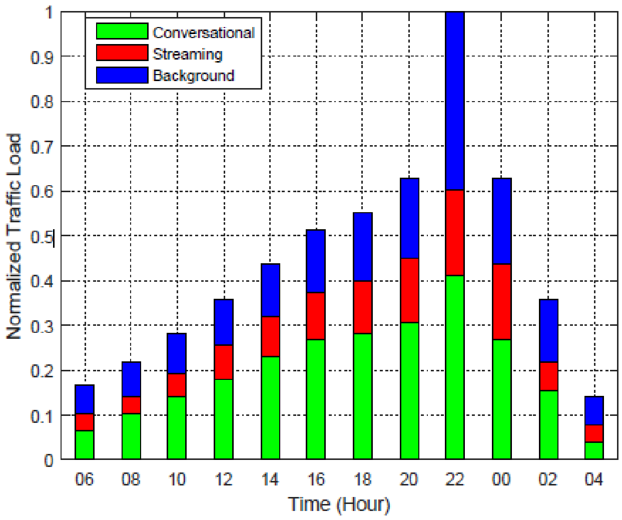

Fig.5. Normalized Peak Traffic Load Profile

On the other hand, background traffic (low priority) suchas email, ftp, and telnet, use network resources when the other two traffic demands are fully satisfied, i.e., looser delayrequirements. The normalized number of required active SCNs is depicted in Fig. 6, where the percentage of active SCNnumbers from lowest to highest order are 0% (5 am), 30% (4pm), 60% (8 pm), and 100% (10 pm). A loadfactor [0,1] was considered in their design for each hour ina day by estimating the maximum, minimum, and averagetraffic collected over a week, where 0 indicates that load dependent components are in sleep mode, and 1 indicates that the cell consumes the highest amount of power.

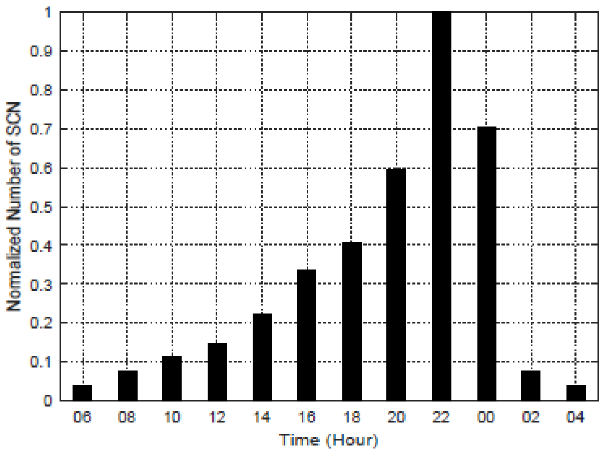

Fig.6. Normalized Number of Active SCNs

A. *Backhaul Network Analysis*

In this section, we present simulated results in terms ofpower consumption for various backhaulsolutions. Detailed simulation parameters for backhaul networks are listed in Table 1. Note that same amount of traffic is considered for backhauling at a particular hour during the 24-hour timeperiods. Fig. 7 illustrates the backhaul power comparisonamong different solutions during various hours of the day.It is apparent that during low (02am to 10 am) and medium traffic periods (12 pm to 6 pm), wireless mmWave solution consumes less power thanany other solutions. The rationale is that a 60GHz mmWave technology assuming 100 m distance betweenSCNs, which requires a transmission power less than 10 dBm.The overall backhaul power for this solution mainly dependson the transmit power consumption.

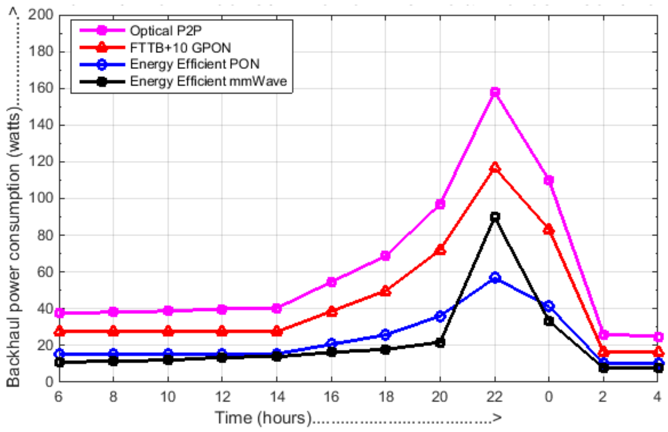

Fig.7. Power Consumption of various backhauling solutions

TABLE 1.SIMULATION PARAMETERS

Parameters	Value
N_{dl}^{max}	24
α	0.9
$P_{sw}^{max}/P_{sw}^{dl}/P_{sw}^{ul}$	300/1/1 W
$P_{modem}/P_{DSLAM}/P_{sw}^{F}$	5/85/300 W
$P_{SFP}/P_{SFP+}/P_{low-c}/P_{high-c}$	1/1/37/92.5 W
$P_{GES}^{max}/P_{sw}^{MW}/P_g/P_o$	50/53/2.9/5 W
$n_{ports}^{D}/n_{ports}^{F}/n_{ports}^{GES}/n_{ports}^{splitters}/n_{sup}^{MW}$	16/24/12/24/16
$Ag_{max}/U_{int}^{max}/C_{sw}^{MW}$	24/10/36 Gbps
$f_{bh}^{mmWave}/W_{\mathcal{M}_k}$	60/1.76 GHz
d	100 m
$L_P/L_{P_0}/L_i/L_{sh}/L_a$	108/68/4/1/3.2 dB

Fig. 7 highlightsthat energy efficient PON solution consumes less powerduring high traffic periods (08 pm to 00 am) than any other solution. At peak traffic load (10 pm), the energy efficient PONsolution consumes the least backhaul power, but the mmWavesolution consumes more power than the FTTB + 10 GPONsolution due to the increase in transmission power from highly dense SCN deployments. The powerconsumption difference between energy efficient PON and FTTB + 10 GPON solution reaches almost 50 W during low traffic periods (02 am to 10 am).From these analyses, it is obvious that duringlow and medium traffic periods of the day, the mmWavesolution performs better than other solutions in terms of powerconsumption. The findings also indicate that the mmWavesolution can be a better choice for low and medium trafficperiods and the energy efficient PON solution is the better option during hightraffic periods.

Since BSs are typically deployed on the basis of peak traffic volume and stayed turned-on irrespective of traffic load, it is possible to save huge energy by switching off some underutilized BSs during off-peak times using switching on/off based energy saving(SWES) algorithm[8][9].

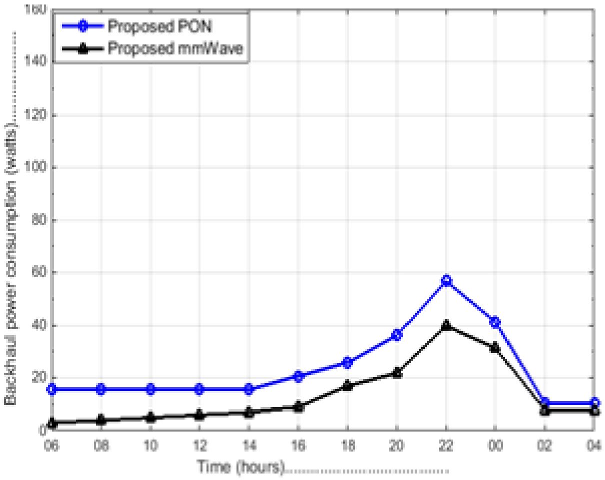

Fig.8 Power Consumption of proposed backhauling solutions

This can reduce the backhaul power consumption of mmWavetechnology during peak traffic loads. Fig. 8 depicts proposed mmWave model saves 38% of power compared to existing model during high traffic hours. Thereby mmWave technology can be used as a better choice during all hours of a day.

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