SC-RAN: An Energy-Efficient Solution Toward C-IoT Implementation

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***Abstract*—The enormous increase of wireless and Internet of Things (IoT) devices increase the traffic load and corresponding number of base station (BS). In this paper, different scenario are investigate to reduce the power consumption by redesigning the BS architecture. Small-cell cloud RAN (SC-RAN) is considered to be a better alternative for reducing the power consumption and dissipation in the dense traffic area. Different issues are discuss related to conventional distributed radio access network (D-RAN) with respect to an SC-RAN. We proposed two different power consumption model for both D-RAN and SC-RAN by giving more focus on the energy control parameter of a base band unit. Simulation is carried out at the different traffic load situation for both types of BS by using TU-Vienna LTE simulator. The simulation result shows that around 40-50% energy can be save by redesign the traditional base station architecture in in to SC-RAN.**

***Index Terms*—BBU-Pool, C-IoT, D-RAN, Power Consumption, RRH unit SC-RAN**

I. Introduction

With the advancement of IoT and other small-scale networks, the key challenge is to design an energy efficient and cost effective cellular network. Cloud RAN or centralized RAN deals with energy and cost optimization. The different cost like capital expenditure (CAPEX) and operational expenditure (OPEX) involved in the BS establishment and operation. Small-cell technology provides solutions which are faced by the today traditional BS architecture. At the current scenario with the fixed number of physical resources, it is very difficult to implement a large number of BS corresponding to the user requirement. C-RAN solves different physical constraint by modifying the BS architecture. As large number of IoT and other wireless devices communicate with each other through BS, the cellular traffic load on the BS is drastically increased. To accommodate this and to get a better quality of services (QoS) the BS should be placed closer to the user. The reduction in size with a smaller BS leads to increase the data rate, network accessibility. and decrease the end to end delay of the access network. However, this small BS has many limitations in term of BS establishment cost and backhaul functionalists. Due to the smaller cell size, problem like; inter-cell interfaces (ICI) and line of sight (LOS) are more challenging. To solve these issues, a centralized architecture is more suitable for this small cell technology, where all the baseband processing is carried out at a centralized location. The development of narrowband IoT (NB-IoT) in the LTE standard, increase network scalability and provide services to massive-IoT network [1]. In this paper, a brief comparison between SC-RAN and traditional D-RAN is carried out interm of power consumption and traffic load. There are many challenges which limits the performance of the traditional D-RAN architecture. Some key challenges and their corresponding proposed solution are listed as below:

- *Issue:* In the traditional distributed BS architecture base band processing and controlling activity is carried out at local base band unit. This leads to a increase in the number of BS by increasing number of user.
- *Solution:* The local small cell access point (SC-AP) or a remote radio head with a RF unit, can be placed any where instead of the big tower. This reduces cellular area and capital cost (CAPEX).
- *Issue:* The point to point connection between antenna unit and base band unit requires a large and expensive co-axial cable. Again more number of BS leads to a more complex backhaul network.
- *Solution:* The SC-AP along with a local processing unit is connected to the main unit through a small optical fiber cable. This makes the architecture scalable and energy efficient.
- *Issue:* As traditional BS are allocated to serve a specific number of user, energy consume by D-RAN is independent of traffic load.
- *solution:* The introduction of centralized processing and controlling of SC-AP make the SC-RAN more scalable and energy efficient.

A. main contributions

The massive use of IoT and digital power hungry devices, increase traffic load as well as power consumption of the next generation BS [2]. Different research and BS manufacturing organization has proposed different solution for energy and cost optimization techniques in their earlier research work. From the literature review, in Section II. we conclude on four key challenges for the next generation C-IoT network i.e.

1) How to reduce power consumption of BS.

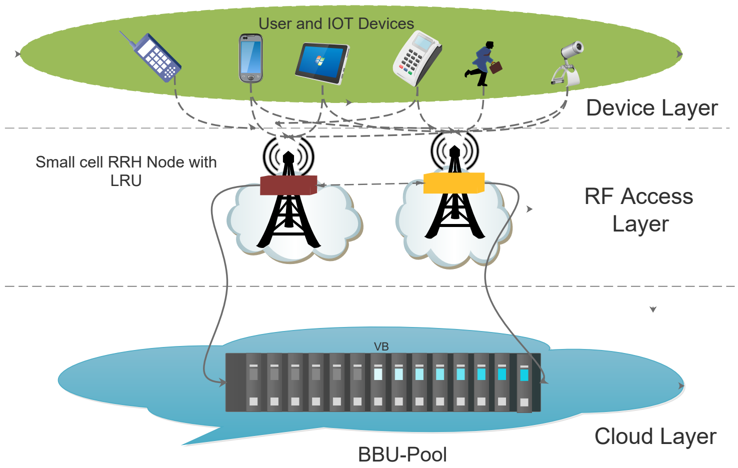

Fig. 1. The LTE based C-IoT Network Architecture consist of four D2D, access and core layer for end to end communication establishment

2) How to decrease network latency and increase data rate.
3) What technique should be used to reduces this power consumption
4) What should be the architecture of this new BS.

This paper, proposed an SC-RAN architecture for large-scale IoT applications. The main contribution of this paper are as follows:

- An energy efficient SC-RAN architecture is proposed.
- Analyze the power consumption by SC-RAN by a detail devices level power consumption calculation.
- Simulation is carried out to analyze the efficency of the proposed system.

B. Architecture of SC-RAN

The SC-RAN architecture consists of a distributed small RRH and a base band unit (BBU). They are connected by some wireless fronthaul link for resources sharing. Fig.1 shows detailed architecture of SC-RAN. The main functional unit are as follows:

- **Antenna and remote radio head (RRH) unit:** This unit consists of a number of sector antenna and small active RRH. Antenna unit performs signal transmission and reception activity and it is connected to the UE through downlink/uplink radio frequency (RF) signal. The local processing unit (LPU) present in RRH is used for signal re-conversion and controlling activity.
- **Fronthaul and Backhaul Link:** The Fronthaul link the RRH and BBU with a optical fiber cable or a large bandwidth microwave signal. The backhaul established a link between BBU to the core network. The backhaul connects all the router, switches and EPC core present in the network.
- **Centralized Base Band Unit (C-BBU)**: This unit performs baseband signal processing over a centralized cloud platform. It process all the signal coming from the RRH unit through the fronthaul link. The control unit residing in C-BBU perform RRH load monitoring and switching activity.

The rest of the paper is organized as follows: Section II describes prior related work. In Section III, architecture of the SC-RAN was described. Section IV, describes the system model and mathematically formulation for energy consumption by different RAN architecture. In section V, simulation results are evaluated. Finally in Section VI, concluding remarks are given.

II. Prior Related Work

As most of the long-range IoT communication is carried out through the BS, this needs a drastic change in the BS architecture to make it more energy and cost efficient. To minimize power consumption and increase the quality of services (QoS), many research work has been carried out. China mobile proposed C-RAN architecture for a metropolitan city for the first time in 2010. On the other hand, IBM and Ericsson mobile have first time introduce virtualization technique at the BBU-pool. This virtualized BBU growth over a conventional data-center by using cloud computing technology. A power optimization technique based on load balancing in a small cell cluster is given in [3]. In [4], authors proposed a Long Term Evolution Advanced (LTE-A) based small cell network. Different power optimization techniques are proposed by reducing the inter-cell interference (ICI) and co-channel interference between macro and small cell. A C-RAN based small cell architecture is proposed to increase the capacity of a cellular network by reducing inter-cell interference and joint optimization technique [5]. These work focused on to reduce the complexity of backhaul and the fronthaul optical network by using Wavelength Division Multiplexing (WDM) on a Passive Optical Network (PON). This paper demonstrates a shared optical infrastructure for two operator co-existences. Though these papers describe some solution for SC-RAN implementation, an ideal concert model for the energy optimization at RRH and BBU of C-RAN are not given. In [6], and [7], Authors proposed an enhanced-RRH (eRRH) model for small-cell implementation in a homogeneous C-RAN. Different solutions to the problem like file handling, cache memory allocation related to the edge based C-RAN architecture are described in this paper.

Some authors have proposed power consumption optimization at the device level. In [8], a dynamic base station switching (BSS) technique proposed for switching On/Off the BS based on the traffic load condition. In [9], dynamic RRH allocation and selection based BBU switching technique is proposed for power consumption optimization. A real-time power consumption model for traditional BS has given in [10], and [11].

III. System Model and Problem Formulation

A. *Traffic Arrival Model at RRH:*

The random distribution of different IoT and UE devices throughout the geographical area, randomly change the load and capacity of the network element. As both the traffic generated by IoT or UE devices is different in term of bandwidth, data rate and service type (uplink/ downlink). The next generation of BS has to entertain both types of devices and their corresponding traffic arrival [12]. In contrast to UEs (smartphone) traffic, almost 80% of the IoT traffic are uplink in nature and needs a higher data rate and low latency. Considering this uplink scenario of an SC-RAN architecture, which operates on an LTE-M band to provide service to $'M'$ number of connected IoT devices. Considering each user request arrived randomly at the RRH with in a specific time period and are generate 'P' number of packets. Taking the references of *Poisson distribution* the probability that 'k' number of UE arrived at BS at 'λ' arrival rate in a 't' interval of time can be express as:

$$P(k) = \frac{(\lambda t)^k e^{-\lambda t}}{k!} \tag{1}$$

Then, probability of single UE arrival in a Δt at the RRH can be represent as:

$$P(k) = \frac{(\lambda \Delta t)^k e^{-\lambda \Delta t}}{1!} \tag{2}$$

$$= (\lambda \Delta t)^k e^{-\lambda \Delta t} \tag{3}$$

This arrival rate, change the load, capacity and power consumption of the corresponding BS.

B. *Power consumption model of SC-RAN*

The power consumption of the SC-RAN depend upon two factor, i.e the traffic arrival rate at the RRH and the BBU processing speed. Again the power consumption of this architecture can be categorized into *dynamic power consumption* and *static power consumption*.

- *Dynamic power:* The power consumption which varies with respect to the incoming traffic load is known as dynamic power. As the SC-RAN RRH is small in size and sensitive to the incoming traffic load variation, this power can be control by implementing different BS switching and load balancing technique. Mathematically the dynamic power of RRH and BBU can be expressed as:

$$P_{rr,dynamic} = (P_{cc} + P_{up} + P_{tx} + P_{fl}) \tag{4}$$

$$P_{bb,dynamic} = M[(\frac{P_{tx}}{\mu_a}) + P_c + P_{sp})] \tag{5}$$

- *Static power:* This is the minimum power consume by a BS under minimum or ideal traffic load condition. This power is generally manufacturer specific and can be reduce by redesign the BS architecture [13],[14]. As in SC-RAN both RF and processing unit are separated, the static power consumption is minimum due to small devices size and low operating voltage and it can be express as:

$$P_{rr,static} = (P_{cc} + P_{up} + P_{tx} + P_{fl})(1 + C_{ps}) \tag{6}$$

$$P_{bb,static} = M[(\frac{P_{tx}}{\mu_a}) + P_c + P_{sp})](1 + C_{ps}) \tag{7}$$

Where
P_{tx}, P_{up}, P_a, P_{sp}, P_{fl}, P_c, P_{cc} are the total power consume by the transceiver, UP/DOWN converter, amplifier, signal processing, rectifier, cooling and controller unit of the base station respectively. $(1 + C_{ps})$ is the power leakage or power supply loss in the RRH and BBU unit.
So the total power consumed by the RRH unit can expressed by adding eq.(4) and (6)

$$P_{rt} = P_{rr,static} + P_{rr,dynamic} \tag{8}$$

And the total power consumed by the BBU unit can be express from equation (5) and (7)

$$P_{bt} = P_{br,static} + P_{bb,dynamic} \tag{9}$$

So the total power consume P_{Tsc} by a SC-RAN system with single BBU unit and a cluster of 'N' RRH unit can be express by:

$$P_{Tsc} = N \times P_{rt} + P_{bt} \tag{10}$$

where:
P_{rt}, P_{bt} are the total power consume by RRH and BBU unit.

C. *Load Consideration and RRH switching of SC-RAN*

The incoming traffic load is consider to be a prime factor for the base station switching. We have taken references of our previous work [16], for threshold value calculation of RRH. If the load contributed by one UE arrival is consider as L_i then total load consider at the RRH for M user arrival can be expressed as:

$$L_T = \sum\nolimits_{i \in |M|} L_i \tag{11}$$

Then RRH load per capacity can be calculated as

$$L_p = \frac{L_T}{\sum_{i \in |M|} Cp_i} \tag{12}$$

Then, threshold of each RRH can be calculated as:

$$TH_k = L_P \times Cp_k \tag{13}$$

where,
Cp = capacity of RRH unit.
The RRH and corresponding BBU On/Off switching decision is based on the threshold value of the load and capacity. A RRH should be switch OFF when very less number of UE are attached with the RRH and the total traffic load, goes below the minimum capacitive threshold limits TH_k of RRH. Which can be mathematically express as:

$$TH_k > \sum_{i \in |Z|} L_i \tag{14}$$

And it is switch ON from ideal mode to an active mode when the total traffic load is greater then the TH_k:

$$TH_k < \sum_{i \in |Z|} L_i \tag{15}$$

where,
$\sum_{i \in |Z|} L_i$ = load generated by users assign at a particular RRH.

D. Dynamic Load Dependent Base Station Switching Algorithm (DLD-BSS)

The small cell base station (SC-BS) are switching On and Off for power optimization based on the load and capacity of the corresponding BS. The BS is switch On when the load of BS goes above the lower threshold limits L_{th}. On the other hand switch Off decision are taken when the incoming traffic load at the RRH goes above the U_{th} or below the L_{th} as mention in Algorithm 1. This dynamically switches On/Off the RRH by migrating its present load to the nearest RRH which are currently handling minimum traffic load.

Algorithm 1: Dynamic Load Dependent Base Station Switching Algorithm (DLD-BSS)

$N \leftarrow$ Initialize the number of RRHs in one cluster
Calculate total traffic load generated by UE or IoT devices
Calculate the present load at RRH
Calculate the threshold value of each RRH
if $L_{RRH} < L_{th}$ **then**
    Switch off the RRH and Migrate the load
    N = N - 1
    Update the load of other RRH
    Update the power consumption
end
else
    if $L_{RRH} > U_{TH}$ **then**
        Switch on the RRH and update the current load
        N = N + 1
        Update the power consumption
    end
end
Release the resources and update the Information

TABLE I
STANDARD POWER CONSUMPTION BY DIFFERENT COMPONENT OF A BASE STATION [15]

BSs parameters	Power consumption (W)
Processing Unit (Psp)	150W
Amplifier Unit (PA)	24 W (Ptx = 34 dBm) 166W(Ptx = 44dBm)
Transceiver	150W
Filter and Rectifier section	110W
Cooling conditioning (Pac)	350 W
Optical or microwave Link unit	90W

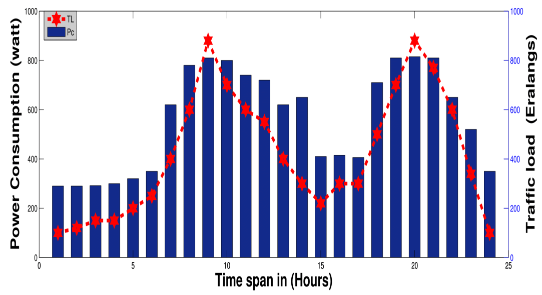

Fig. 2. Average traffic arrival vs Power consumption of a BS

IV. SIMULATION AND RESULT

In this section, the different RAN performances analysis is carried out based on the power consumption with respect to the traffic load variation. In this work, we consider a homogeneous SC-RAN system as shown in Fig.3B, where all RRH and BBU are having same characteristics and unique set of parameters. We have used LTE-Tu. Vienna simulator for simulation of SC-RAN and a traditional RAN [17]. Taking the reference of TABLE I, we have calculated the total power consumption of the SC-RAN and D-RAN. In the first phase of the simulation, we have taken a traditional BS which has a larger transceiver power and a larger coverage area. The traffic load is generated by assigning a number of UE to the BS. Then the traffic load is increased in equal percentage from 10% to 100%. The output shown in Fig.2 shows the relationship between traffic arrival and the corresponding power consumption of a traditional BS. In the second phase of the simulation, we have taken three small cell transceiver which contains three RRH unit {R1, R2, R3} and a centralized BBU unit C-BBU. By assigning an equal percentage of traffic load, the corresponding power consumption (Pc) is evaluated as shown in TABLE II. Fig.4 shows a power consumption versus traffic load comparison for both D-RAN and SC-RAN architecture. Fig.5 shows the total power consumption for both types of RAN over a period of 24 Hours. This figure clearly shows that SC-RAN consumes around half of the power under the same traffic load condition. Also, the power consumption is more scalable as compared to the D-RAN. This linear effect of traffic load on the power consumption makes the SC-RAN architecture more energy efficient and suitable for next-generation IoT application.

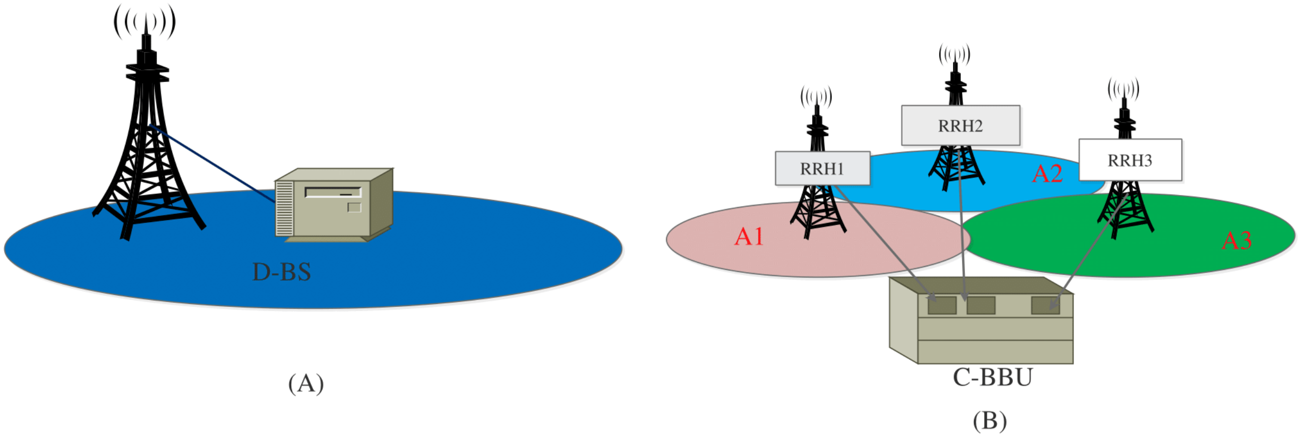

Fig. 3. Power consumption comparison between a cluster of SC-RAN and a D-RAN having the equal coverage area

TABLE II
POWER CONSUMPTION ANALYSIS OF SC-RAN AND TRADITIONAL DISTRIBUTED RAN

Type of BS	Size of Cellular Area (km^2)	Cellular Area	Pc at 10% Traffic Load	Pc at 50% Traffic Load	Pc at 100% Traffic load
Total power consumption (W) for a three cell D-RAN cluster area for 24h Run			340	810	850
SC-RAN	$3\times5 = 15km^2$	C1 = RRH1	45	80	130
		C2 = RRH2	35	85	126
		C3 = RRH3	46	110	140
		C-BBU	85	125	156
Total power consumption (W) for a three cell SC-RAN cluster area for 24h Run			211	400	552

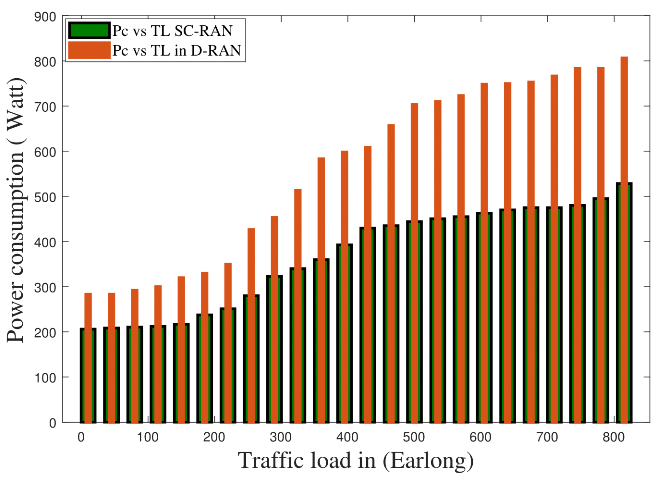

Fig. 4. Power consumption vs Traffic load of a Traditional base station (D-BS)

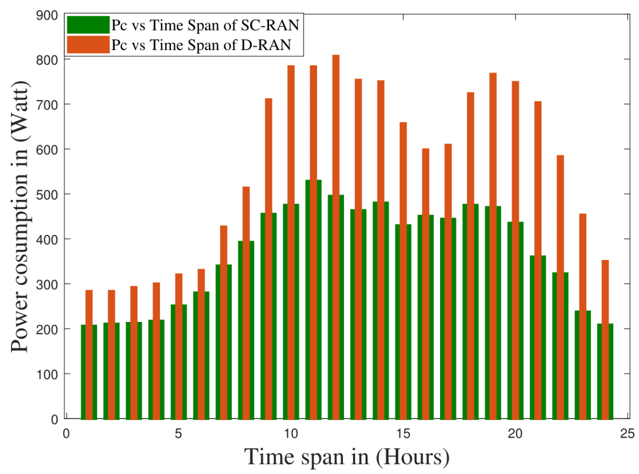

Fig. 5. Power consumption vs Traffic load of a Traditional base station (D-BS)

V. CONCLUSION

The evolution from the Traditional RAN to the Centralized RAN can benefit both the user and service provider in term of energy efficiency, CAPEX and OPEX. The new C-RAN architecture realized to be more spectrally efficient in terms of bandwidth utilization and spectral efficiency. In this paper, we have proposed a power consumption model for both traditional D-RAN and SC-RAN for a C-IoT network. During the power consumption modeling, we have considered both dynamic and static power consumption by the BS. This mathematical modeling focused on a devices level power consumption for both types of BS. The different measurement shows that the power consumption of a BS can be reduced by introducing dynamic PA, centralized cooling and dynamic base station switching technique. The simulation result shows that due to centralization and small cell technique BS power consumption can be reduce 40%-50% as compared to the traditional BS. This energy efficient property also reduces the corresponding cost incurred for BS installation and maintains.

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