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Power Utilization Analysis for Centralized and Distributed Antenna Systems

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ABSTRACT: Mobile network data rates are increasing with each generation, due to the usage of emerging technologies and advanced architectures. They may consume substantially more power than the present fourth-generation (4G) and fifth-generation (5G) systems. Base stations have been determined as the primary source of energy usage in a mobile network. They are responsible for more than 60% of the energy consumption of mobile networks. Moreover, the recent 5G base stations (BSs), which provide higher bandwidth and data rates and have more transceivers with centralized antennas, raise alarms about their power consumption. With eco-friendly concerns about the amount of carbon dioxide (CO_2) reduction, the intergovernmental panel on climate change (IPCC) sees climate change as a threat to human well-being and planetary health, and ever-increasing energy costs have already created an urgent need for more energy-efficient and low-power consumption BSs in mobile communications. As a result, the energy consumption and carbon emissions of 5G mobile networks are concerning. Information and communication technologies (ICTs) have great potential for reducing CO_2 emissions. Therefore, power consumption is one of the central topics for telecom network providers, especially when they are challenged by higher costs. The distributed antenna system consumes more than 35% less power than the usual centralized structure; thus, swapping a centralized antenna with a distributed antenna may lower total power consumption.

1. INTRODUCTION

Science and technology advancements are changing the way we live and work. Constantly growing and improving technology, such as fifth-generation (5G), beyond-fifth-generation (B5G), and sixth-generation (6G), provides unlimited creative thinking in academia and industry.

Mobile communication networks require much higher data rates and rise with each generation, potentially requiring substantially more power than current fourth-generation (4G) and 5G systems. According to recent projections, the number of connected devices will exceed 100 billion by 2030 [1], with 5G networks potentially supporting up to 1000 times more data than 4G networks in 2018 [2]. While mobile data traffic has increased rapidly due to a variety of services and mobile applications, so has power consumption.

The energy utilized by communication networks grows rapidly [3], resulting in rapid cost increases for both network providers and end users [4]. Information and communication technology (ICT) accounts for around 3% of global energy consumption and 2% of global CO_2 emissions, with mobile and wireless networks accounting for 57% of energy usage. The operation of macro-cell base stations is expected to require around 60% of the energy in a cellular network [5]. As a result, it is predictable that base stations account for the majority of radio network greenhouse gas emissions. Most mobile communication techniques aim to increase performance indicators such as throughput, quality of service (QoS), and reliability, while putting less focus on power consumption. However, there are now debates and considerations about the energy consumption of network devices in open radio access networks (O-RANs) [6]. Energy saving in mobile communication systems is strongly related to minimizing the transmission power consumption of base stations (BSs). As a result, several studies have been conducted to reduce BS power usage [7]. Thus, in order to transition to the future green radio environment with considerable CO_2 reductions, energy-efficient mobile communications must attain faster data speeds while consuming less power. It has been previously demonstrated that the power consumption of BSs is influenced by that of each individual element, with radio frequency (RF) equipment consuming most of the power [8, 9]. Ref. [5] describes ways to conserve energy for mobile communication using various mechanisms.

The cell radius, or the maximum distance between the transceiver and user equipment, and BS power level are critical elements in the design of a power-efficient cellular system. Cell architectures are classified according to cell size into macro-, micro-, pico-, and femto-cells. Saving energy is a vital call, but it should not come at the expense of performance or coverage. We could not save too much energy if the performance dropped to an undesirable level of the QoS expected by users. As a result, power-saving solutions should strive for optimal energy efficiency, above the acceptable QoS level. Although it can be hard to build power-saving solutions for optimal energy efficiency which save a lot of energy while still providing similar performance, the main difficulty is the tradeoff between energy consumption and obtained performance. In terms of power usage, BS components are not

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independent of one another. As a result, each unit cannot be stated using a single constant without taking into account the connection relations.

Aside from the use of energy, one difficulty in urban locations is how to enhance network capacity to manage the rapid growth in data traffic. To maintain communication coverage, a distributed antenna system (DAS) requires a large number of access points (APs) with low transmission power levels. In contrast, a co-located-based system necessitates a small number of BSs with a high transmission power level.

Antenna arrays are an important factor in the development of wireless systems. Using several transmitting and receiving antennas improves radio connectivity. The multiple-input multiple-output (MIMO) antenna improves communication performance by enabling beamforming and antenna diversity. With beamforming capabilities, the power of transmitted signals can be directed at individual users. With antenna diversity, the same transmitted signal is routed across multiple channels, allowing the receiver to choose the best version of the signal. Massive MIMO (mMIMO) allows for aggressive multiplexing, channel hardening, and data rate increases while substantially raising the number of antennas [10].

The usage of mMIMO in 5G systems at higher frequency bands will effectively compensate for path loss. However, mMIMO antennas are not practical in the sub-3 GHz or 3–6 GHz bands [11, 12].

Communication in millimeter-wave (mm-wave) frequency bands, also known as 5G new radios (NRs), presents a number of issues, one of which is the high propagation loss and sensitivity to obstruction from nearby objects and materials. However, due to the short wavelength in the mm-wave band, a high number of antenna elements in the form of mMIMO might offer directional communication with beamforming gain and compensation for propagation losses. However, these directional linkages need exact beam alignment at both the transmitter and receiver [13].

Organizing and assembling a large number of distributed antennas brings radio frequency (RF) sources closer to users. This method is especially useful for mm-wave communications, where the RF propagation range is limited and extremely directional. Pathloss (PL) information is critical when system performance is assessed [14–19]. Moving antennas closer to users can improve communication quality in terms of coverage and interference management, particularly in areas with high density.

To deliver geographically uniform services to consumers, a large number of distributed antennas via APs can be placed. There are several architectures for implementing distributed antenna systems, including cell-free CF-mMIMO [20] and cloud radio access network [21] systems. In such systems, the baseband unit (BBU) can be relocated to a central unit (CU) to save power and operating costs. By expanding the number of APs and their accompanying antennas, a large number of antennas are installed around the user equipment (UE), focusing energy on each UE [22, 23]. In this study, we investigate the effect of cell size on power consumption in relation to the distance between the antenna unit and the UE.

The rest of this paper is as follows. To have a better view of distributed antenna systems, details on DAS and its features are explained and discussed in Section 2. The system model is expressed in Section 3. Optical links are discussed in Section 4. Energy consumption of centralized and distributed antennas for varying distances to user equipment is provided in Section 5. The power consumption breakdown and results are presented in Section 6. Lastly, concluding remarks are given in Section 7.

2. DISTRIBUTED ANTENNA SYSTEM

The continuous expansion of data throughput in upcoming years will call for more efficient wireless technologies to cope with the increasingly extreme data rate of the previous wireless communication system. Massive MIMO is one of the most important key technologies in 5G and B5G, and it is expected to remain relevant in all future mobile communications. Although most of current literature assumes mMIMO to be a centralized antenna array deployment, the distributed antenna system has a number of advantages over centralized antenna deployment [24]. Furthermore, distributed MIMO system may become increasingly important [25].

Unlike in a traditional cellular network, where antenna units are centralized at a single place, DAS antenna units are geographically scattered to reduce access distance and are linked to a central unit via a dedicated high-speed optical fiber network. The distributed antenna system may be traced back to the use of large cells and the replacement of each central station's single antenna with a distributed antenna system, or leaky feeder. It was first introduced to effectively cover dead areas in indoor wireless communications [26]. Distributed antenna systems do not need sophisticated antenna units and require less electricity than central antenna systems [27]. The structure of a DAS with its BS in a cell area is shown in Fig. 1.

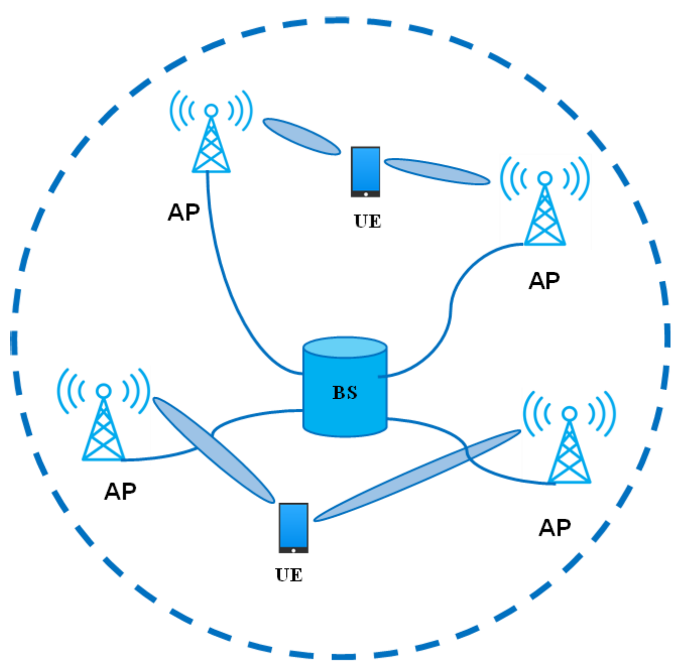

FIGURE 1. Distributed antenna deployment structure.

It can be seen that a distributed antenna system mainly consists of several antenna units geographically separated from each other in the coverage area, which are connected via optical fibers to the central unit to transfer information and signaling between the distributed antennas and central processor, where all signals are jointly processed.

From an architectural standpoint, DAS provides clear advantages over conventional systems. DAS can reduce the number of base stations necessary within a specific service region, lowering installation costs and simplifying maintenance [28]. Because the distributed antenna units and the CU work together to provide a macro-MIMO vector channel, DAS can also be thought of as a macro-multiple-antenna system [29]. Furthermore, due to the widely dispersed antennas in DAS designs, macroscopic fading (path loss only) across various antennas is generally independent [30]. A distributed antenna system is widely regarded as an extension of MIMO technology since it has the ability to reduce other-cell interference (OCI) by lowering overall transmitted power while enhancing coverage and capacity [31].

The DAS arrays have substantial power and capacity gains over centralized arrays. With 16 antenna elements, a DAS array potentially offers transmission power savings up to 15 dB and a three-fold capacity gain [32]. The DAS benefits strongly from macrodiversity due to the widely spaced antenna units, and they therefore have the capability to enhance signal quality, increase system capacity, and reduce access distance [33]. Furthermore, the use of multiple APs not only provides a very widespread footprint but also covers high-rise structures too, as shown in Fig. 2.

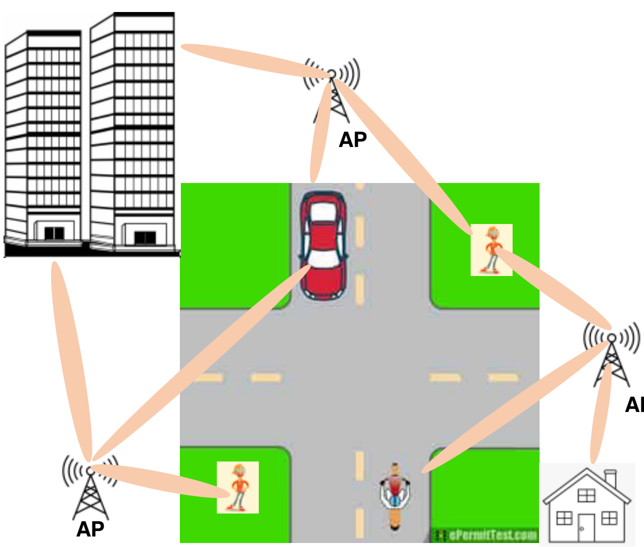

FIGURE 2. Distributed antenna system transmission.

Furthermore, the flexible structure of DAS allows for reform and expansion on the same platform because the size of DAS can be easily adjusted; hence, DAS can serve a wide range of applications with non-interfering and smart coverage. AP antennas allow each user to communicate with several antennas at the same time, no matter where they are in the system. As a result, compared to conventional antenna architecture systems, DAS can achieve more capacity and coverage while using less power and incurring lower expenses [34]. However, the total number and distribution of antennas have an impact on their performance.

The third generation partnership project's (3GPP) long term evolution-advanced (LTE-A) release 10 (R10) investigated into distributed antenna systems. In R10, DASs were viewed as a sort of intra coordinated multipoint (CoMP), intra-CoMP, in which the coordinated base stations share the same site rather than interacting via backhaul information exchange between base stations located at various sites. A more in-depth research of DASs was conducted for 3GPP LTE-A release 11 (R11), with a heterogeneous network as an expected application case [35].

Distributed antenna systems are a significant player in network architecture in forthcoming communication networks. A distributed antenna unit has a number of advantages, such as low transmission power, simplicity, and low cost. Moreover, it can achieve seamless coverage [36]. A study on the system capacity of a distributed antenna scheme showed that with four distributed antennas in each cell, better capacity performance can be obtained [37]. Distributed mMIMO (D-mMIMO) that incorporates both mMIMO and DAS has shown great potential regarding capacity and energy efficiency, and it has been considered a promising technology for future generations of wireless networks [38]. Even though it is widely recognized that the distributed antenna architecture compared with a centralized single antenna structure provides more efficient utilization of space resources, a larger effective area, and higher flexibility, the optimal antenna placement needs further investigation.

3. SYSTEM MODEL

To design cellular network communication, many factors must be considered, including radio coverage, spectrum efficiency, radio frequency propagation and path loss, and quality of service. However, cell radius and BS power level are the most important criteria in cellular system design. It is important to note that in a typical macro base station with two transmitting antennas, when the transmission power is reduced from 40 W to 20 W, the overall power consumption of the macro base station decreases from 1263 W to 838 W, saving more than 30% of power [39]. Propagation model and path loss are two of the most significant factors to consider while planning radio coverage.

It is obvious that any energy efficiency indicator for a radio network should include the network's power consumption, which is dependent on the transmission powers of each individual base station inside the network [40]. Fig. 3 depicts a system with a standard macro-cell model and a central antenna system for downlink transmission with a fixed cell area of Ac and a cell radius of Rc, solely considering the base station transmission power, consisting of BS, a centralized antenna, and user equipment.

Figure 4 depicts a distributed antenna system at downlink transmission with a cell area of A_{AP} and a cell radius of R_{AP}, only considering the AP transmission power.

As the cell area gets bigger, the distance between the transmission antenna and user equipment increases due to the in-

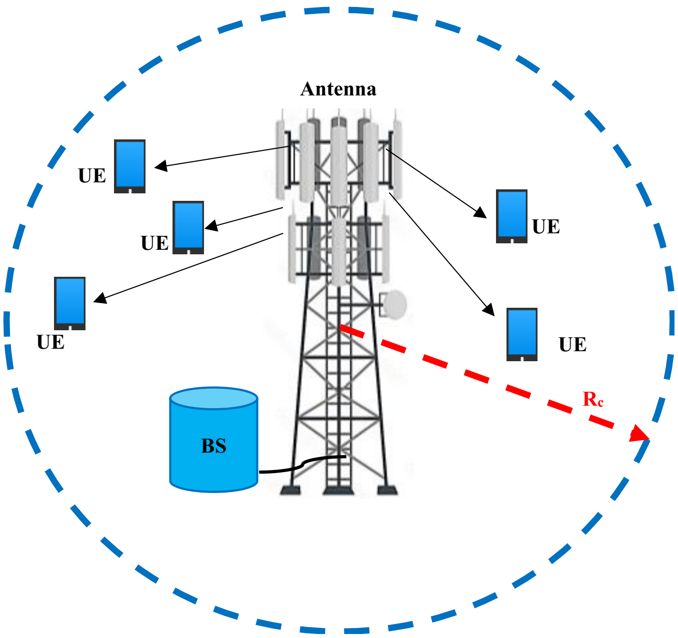

FIGURE 3. Centralized antenna cell architecture.

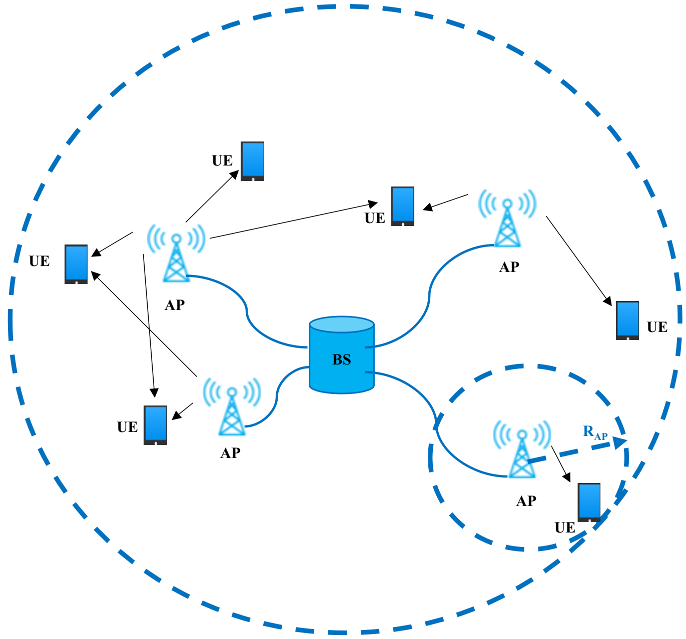

FIGURE 4. Distributed antenna cell architecture.

creasing cell radius. The transmitted power of the base station and propagation path loss also increase [41, 42].

By reducing the cell radius and, as a result, the cell coverage area, the number of users per area decreases, leading to a greater bandwidth per user. Moreover, cell size reduction increases spectral reuse and, hence, increases data rates for UEs. Cell size reduction can be achieved by moving from a centralized antenna architecture to a distributed antenna architecture, where each AP provides small cell area coverage much closer to the UEs.

For the generalization and simplicity of further modeling development, we assume that each antenna corresponds to one user in the cell area for both the central antenna cell and distributed antenna cell architectures. This allows the development of power consumption comparisons with only cell area and radius.

4. OPTICAL LINKS

Employing distributed antennas brings APs closer to users, where distributed antennas, or APs, are connected to a CU through an infrastructure of optical fronthauls, which is responsible for the coordination. Therefore, the power consumption of the optical fronthauls needs to be well thought out. To generate and transfer microwave signals over fiber, three main optical techniques are available: baseband-over-fiber (BBoF), intermediate-frequency-over-fiber (IFoF), and radio-frequency-over-fiber (RFoF) or radio-over-fiber (RoF) [43–46]. The RoF system takes in the original RF signal transmitted over the fiber. However, the BBoF and IFoF required upconversion techniques. Therefore, the complexity and power consumption of AP depend on the method of transmission.

The complexity and power consumption of APs in BBoF and IFoF systems are much higher than in RoF systems due to the complex signal processing and RF up-conversion performed at the AP [47]. However, a frequency conversion is not required in the RoF, and all the RF signal processing steps are centralized and then distributed to APs, enabling a simple, low-power, and cost-effective implementation.

The IFoF based system fronthaul could provide flexible bandwidth allocation and bandwidth-efficient transmission, since multiple IF carriers could be transmitted using a single wavelength. However, it increases the complexity of the AP by requiring additional frequency converter circuitry, which increases power consumption [48].

The primary issue for dense 5G topologies is to dramatically simplify the optical hardware of the APs. Given the multiple cell sites that must be placed to support the cell densification of 5G topologies [49], decreasing the size, cost, and power consumption are critical criteria for the overall system [50].

The architectures of the BBoF, IFoF, and RoF are shown in Fig. 5. The architecture of a BBoF scheme is shown in Fig. 5(a). It consists of BBU, which supports a number of functions such as coding and decoding, digital modulation, digital beamforming, equalization, and channel estimation. The signal conversions between the electrical and optical domains are done by the electrical/optical (E-O) and optical/electrical (O-E) interfaces through laser diodes and photo detectors. The digital signal processing (DSP) unit supports a digital upconverter, a digital predistorter, and a digital-to-analog converter. The RF unit upconverts baseband signals to RF signals. To have a clear border on the bandwidth of the RF signal to fit the allocated RF channel, a bandpass filter (BPF) is used. Finally, RF signal amplification is done by the power amplifier (PA). As shown in Fig. 5(a), the signal is transported optically as baseband data, and the wireless signal is managed completely at the remote AP. In this scheme, data is transmitted in a digital format with a simple structure

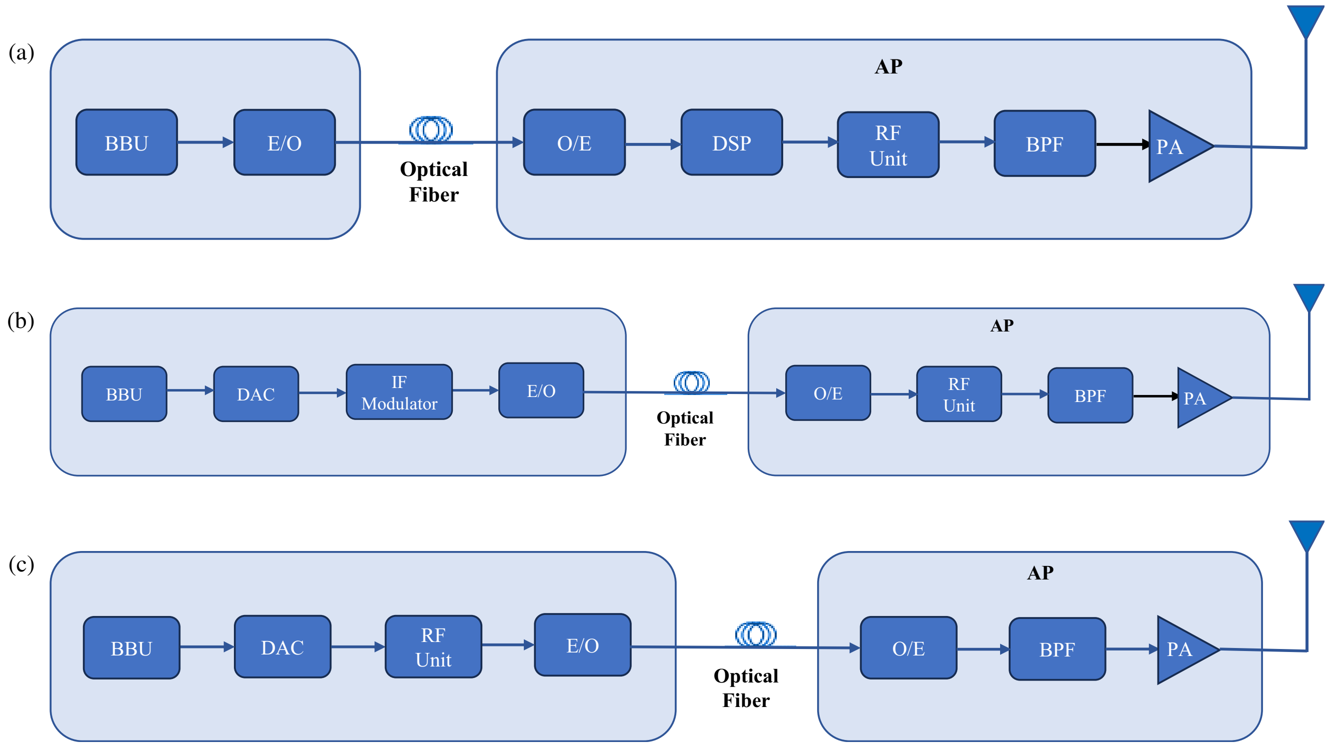

FIGURE 5. Schematic architectures of (a) BBoF, (b) IFoF, and (c) RoF.

in the CU. However, remote AP required additional hardware, which increased the AP complexity.

Figure 5(b) depicts the architecture of an IFoF scheme, in which a wireless signal transmits at a lower intermediate frequency (IF) of a few hundred MHz, so the usage of IF can assist relaxing the hardware requirements of high-speed optoelectronics. Furthermore, the optical distribution of the IF signals has a far lower fiber chromatic dispersion effect. However, these benefits come at the expense of a more sophisticated remote AP design that requires a steady local oscillator (LO) and mixers for frequency up-conversion [51].

Figure 5(c) shows the architecture of an RoF scheme. It is the simplest method for transmitting wireless signals via an optical fiber fronthaul network. It transmits wireless signals directly at the wireless carrier frequency, with no additional frequency processing at the base station. In this design, wireless signals are modulated onto an optical carrier, which is then transferred in analog format over the optical link. The AP in RoF links is significantly simpler than that in BBoF and IFoF links. As a result, the cost and power consumption of APs in a RoF system are significantly lower than BBoF and IFoF. This is especially useful in systems with a high number of distributed APs [47].

5. CENTRAL ANTENNA AND DISTRIBUTED ANTENNA SYSTEMS

In a distributed antenna system, due to the large number of antennas, the optimization of the antenna locations can be highly challenging. Hypothetically, antennas in a DAS can take on arbitrary locations and topologies. However, in a practical deployment, it is more realistic to consider a manageable antenna topology. In this paper, we consider circularly located centralized and distributed antennas, where antennas are on a circle, centered at the cell center. A circular antenna arrangement has been shown to have good performance [52, 53].

Figures 6 and 7 show our approach to evaluating the energy consumption of a BS with a centralized antenna and a BS with a distributed antenna while having a different cell size. To evaluate the power consumption, we considered two cell sizes with different distances to the UE at the boundary of the cell. Moreover, we considered that they will receive the same amount of received power, and the transmitter has a fixed transmission power without any changes with respect to the traffic load.

The cell parameters for a centralized antenna plan are:

P_c: Transmitted power of the central antenna.

P_R: Received power on user equipment.

R_c: Radius of cell area.

P_{A_c}: Power in the area covered by the centralized antenna.

As shown in Fig. 6, a massive multiple-input multiple-output antenna with a large number of antenna elements can be considered a centralized antenna in a macro-cell.

The 3rd generation partnership project (3GPP) Release 15 suggested that beamforming be used to improve 5G transmission and coverage. A minimum of 2×2 antenna arrays are required to generate beamforming beams. Hence, a 5G transceiver must support a minimum of four transmitters and four receivers (4T4R) [54]. As shown in Fig. 7, a 2×2 antenna array is considered an access point antenna for the distributed antenna architecture.

The cell parameters for a distributed antenna plan are:

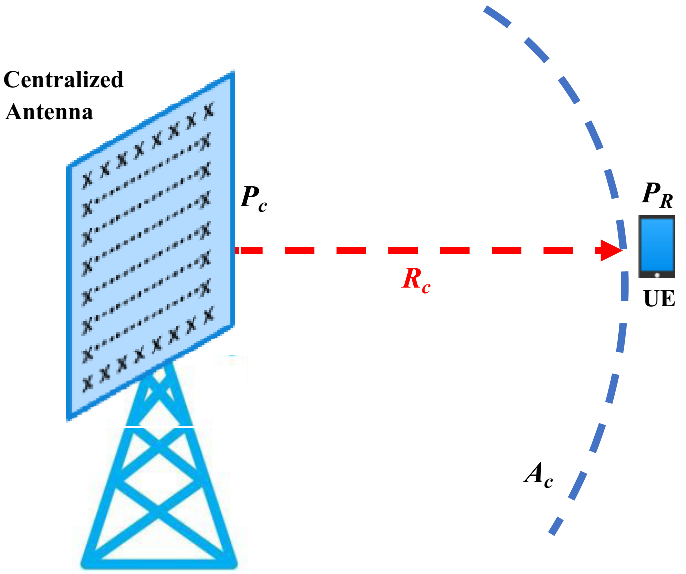

FIGURE 6. Centralized antenna plan.

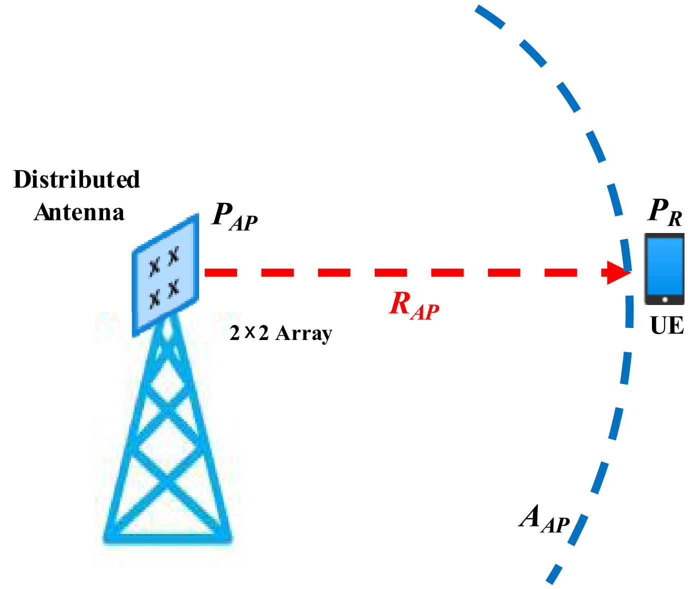

FIGURE 7. Distributed antenna plan.

P_{AP}: Transmitted power of the access point antenna.
P_R: Received power on user equipment.
R_{AP}: Radius of cell area.
$P_{A_{AP}}$: Power in the area covered by the access point antenna.

5.1. Propagation Model

For estimating a transmitter's radio coverage area, propagation models that anticipate the mean signal strength for transmitter-receiver separation distance are critical. A radio channel poses a severe challenge as a medium for reliable wireless communication. Propagation modeling is the fundamental method of predicting the range of a mobile radio system. Pathloss would determine the signal strength shown on the UE. The accuracy of the path loss estimation is critical in defining whether a particular system design will be practical. In macro-cells, empirical models have been used with great success, such as the Okumura-Hata model, which is based on an extensive series of measurements made in and around Tokyo city and has been found useful in many cases [55]. A modeling of radio link budget at mm-wave frequency bands with antenna arrays and analog beamforming, where a single RF chain per polarization is connected to the antenna array, and beam steering is realized by analog phase shifters, is discussed in [56]. The requirements of 5G channel modeling and an extensive review of the channel measurements and models are presented in [57].

Weakening of signal quality due to propagation is related to path loss, slow fading, and fast fading. A simple path loss model that does not include shadowing effects (obstacles between the transmitter and receiver that attenuate signal power through absorption, reflection, scattering, and diffraction) generally assumes that the path loss is the same at a given transmitting-receiving distance [58], as follows:

$$P_R = P_T K \left(\frac{d_0}{d}\right)^n \tag{1}$$

where P_R, P_T represent received and transmitted powers; K is a constant factor; d_0 is a reference distance; d is a propagation distance; and n is the path loss exponent, respectively. The path loss exponent indicates the rate at which the path loss increases with distance, and it is a function of environment, obstructions, distance, and frequency. It typically ranges above 2. The 3GPP models for sub-6 GHz frequency bands have detailed path loss models for user equipment [59] and base stations [60] for different amounts of multipath delay spread, user speeds, and MIMO antenna correlations.

5.2. Power Model and Coverage Area

The cell radius should be as large as possible to reduce the cost of installation per subscriber, but as small as possible to maximize the number of consumers that the system can handle. As a result, the cell radius might be chosen by balancing these two factors. In general, reducing the cell radius by a factor also reduces the transmitted power. The transmission power of BS is proportional to both cell radius and area power consumption, which is power consumption per unit area [61]. A DAS works by forming a single, unified cell that provides blanket coverage within its designated area.

From Fig. 6, the received power at UE can be written as:

$$P_R = P_c K \left(\frac{1}{R_c}\right)^n \tag{2}$$

There are several approaches to estimating coverage areas, each with advantages and disadvantages, but none are completely accurate [62]. The coverage area is a portion of the cell area with the received power above or equal to the required minimum received power. The coverage area can be written as:

$$P_{A_c} = \frac{1}{A_c} \int_{A_c} R_c \cdot P_R d_R d_\emptyset \tag{3}$$

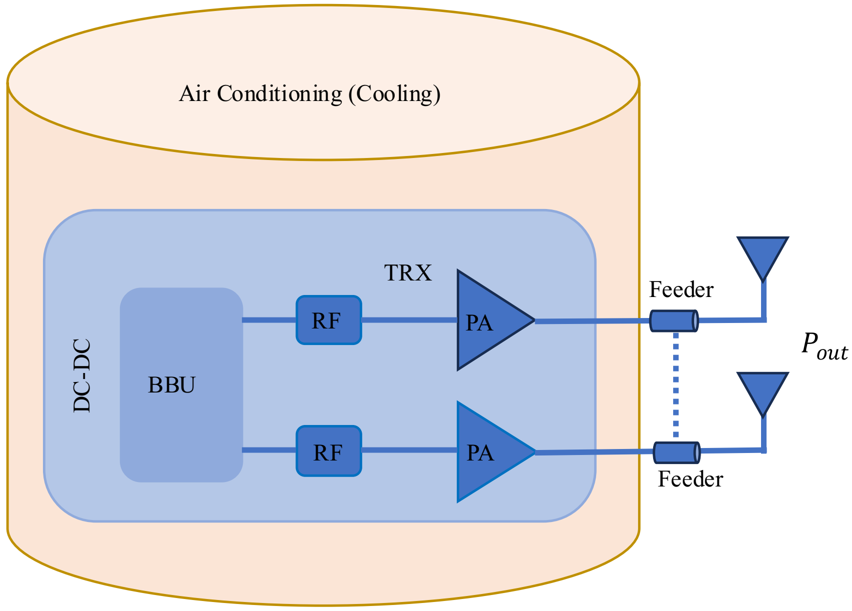

FIGURE 8. Block diagram of a base station.

where P_R (received power) at the given location should be as $P_R \geq P_{\min}$.

The APs feature only a single antenna and cover a much smaller area with a shorter cell radius. They are provided by low-power and low-cost radio equipment. In turn, APs feature much lower power consumption. From Fig. 7, the received power at UE can be written as:

$$P_R = P_{AP} K \left(\frac{1}{R_{AP}}\right)^n \tag{4}$$

In the case of DAS, the coverage area is defined as a segment of the AP area where received power is above or equal to the required minimum received power. The coverage area can be written as:

$$P_{A_{AP}} = \frac{1}{A_{AP}} \int_{A_{AP}} R_{AP} \cdot P_R d_R d_\emptyset \tag{5}$$

where P_R (received power) at the given location should be as $P_R \geq P_{\min}$.

From (2) and (4) the relationship between transmitted power and received power with respect to the cell radius, while each received power level at the cell boundary is set to be equal to P_R, we can obtain:

$$P_c K \left(\frac{1}{R_c}\right)^n = P_{AP} K \left(\frac{1}{R_{AP}}\right)^n \tag{6}$$

From (6), we can obtain:

$$\frac{P_{AP}}{P_c} = \frac{R_{AP}^n}{R_c^n} \tag{7}$$

From (3) and (5), the ratio of the transmitted power in a given area ($A = \pi R^2$) can be realized as [63]:

$$\frac{P_{A_{AP}}}{P_{A_c}} = \frac{P_{AP}}{P_c} \times \frac{A_c}{A_{AP}} = \frac{R_{AP}^n}{R_c^n} \times \frac{R_c^2}{R_{Ap}^2} = \left(\frac{R_{AP}}{R_c}\right)^{n-2} \tag{8}$$

As mentioned earlier, the path loss exponent typically ranges above 2; therefore, from (8), a centralized architecture requires more power and, as a result, more power consumption.

6. POWER CONSUMPTION BREAKDOWN AND RESULTS

To evaluate the BS power consumption, the effect of transmission power and its outcome on the total power consumption need to be analyzed. The base station consists of baseband unit (BBU) and remote radio unit (RRU) parts. RRU is a distributed antenna of the cell; hence, it can be considered an AP, and in fact, it creates a distributed antenna architecture [64]. Since different types of BSs have different hardware components at BBUs, it is difficult to have a uniform approach to evaluating the power consumption of BBUs in different types of BSs.

Considering the functions and architectures of BSs, Fig. 8 shows a whole but simplified block diagram of a base station [63]. A base station consists of multiple radio frequency chains (N_{TRX}), in which each serves one transmitting antenna element.

Figure 9 shows an illustration of a BS with a co-located antenna, while Fig. 10 illustrates a DAS architecture [63].

The base station power consumption grows with the number of RF chains (N_{TRX}). The BS power consumption can be calculated from [65]:

$$P_{PC} = N_{TRX} \cdot \frac{P_{PA} + P_{RF} + P_{BB}}{(1 - \sigma_{DC})(1 - \sigma_{MS})(1 - \sigma_{cool})} \tag{9}$$

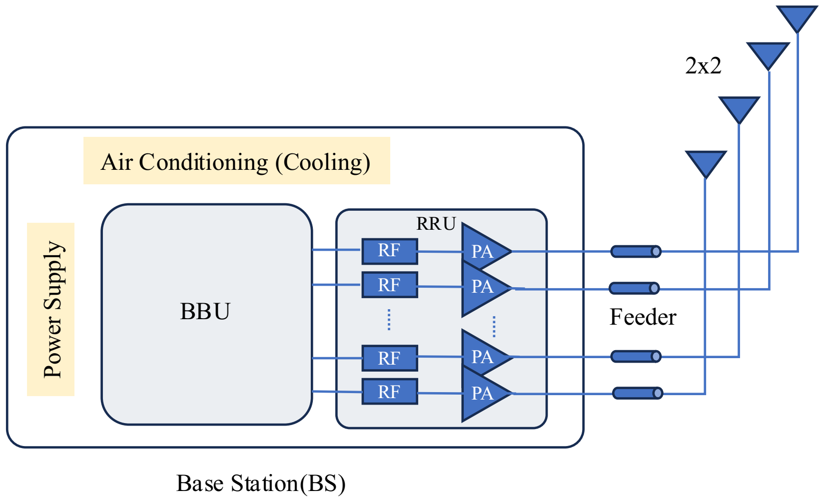

FIGURE 9. Block diagram of a base station with a centralized antenna.

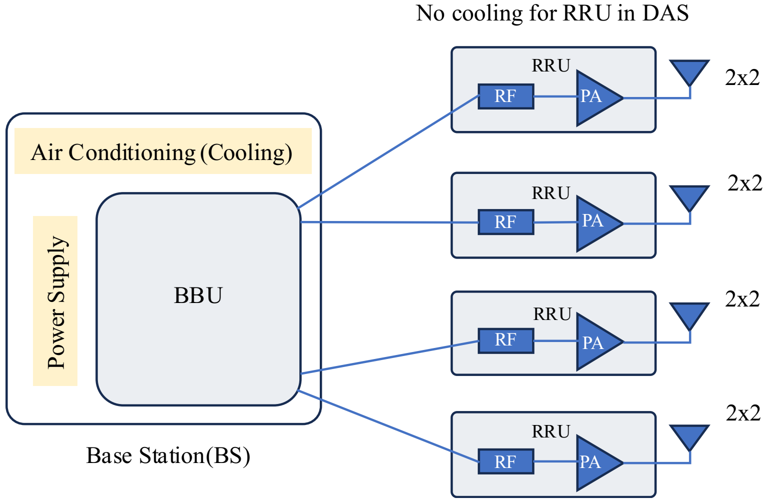

FIGURE 10. Block diagram of a base station with a DAS.

where:

$$P_{PA} = \frac{P_{out}}{\eta_{PA\cdot(1-\sigma_{feed})}} \tag{10}$$

where P_{PC} is the total power consumption (at max load), N_{TRX} the number of RF chains, P_{out} the output power ($P_{out} = P_{\max}$), η_{PA} the power amplifier efficiency, σ_{feed} the feeder losses, P_{RF} the power of small-signal RF transceiver, P_{BB} the baseband power consumption, σ_{DC} the DC-DC power supply losses, σ_{MS} the main supply losses, σ_{cool} the active cooling scale losses, and P_{PA} the power consumption of the power amplifier. Table 1 summarizes the details of the data on power consumption discussed in [63, 65] for macro and RRU antenna configurations which measure the power consumption from real wireless networks.

Table 1 shows the power savings of the RRU heads (i.e., DAS), where feeder losses and active cooling are evaded by placing the power amplifier close to the transmit antenna, resulting in less required power. The reduction of the RF power is based on the fact that the path loss and thus the transmission power increase faster with the inter-site distance (the power coefficient is greater than 2) than the covered area (the power coefficient of 2). For a distributed antenna, the stationary part of the power becomes dominant, and this leads to the lowest total power consumption. The distributed antenna architecture is the key to reducing power consumption.

Figure 11 shows the power consumptions of macro and RRU cells for varying numbers of transceiver units. Assuming that the BS power consumption increases with the number of transceivers, it is obvious that in the case of a big cell radius with a centralized antenna, the power consumption is much greater than that in the case of a small cell radius with a distributed antenna. Results confirm that the amount of power consumption for RRU is much lower than the macro architecture, which was expected with respect to (8).

As can be seen in Fig. 11, the relations between RF output power with respect to the number of N_{TRX} and power consumption are nearly linear. Hence, a linear approximation of the power model could be acceptable. The linear model of BS power consumption is discussed in [40, 65, 66].

TABLE 1. LTE BS transceiver power consumption for macro (centralized) and RRU (distributed) arrangements.

Item	Note	Unit	Macro	RRU
PA	Max transmit (rms) power (P_{max})	W	39.8	20.0
	Max transmit (rms) power	dBm	46.0	43.0
	PAPR	dB	8.0	8.0
	Peak output power	dBm	54.0	51.0
	Total PA $P_{PA} = \frac{P_{out}}{\eta_{PA}}$	W	102.6	51.5
TRX	Max transmit (rms) power	dBm	– 8.0	– 11.0
	P_{TXDC}	W	5.7	5.7
	P_{RXDC}	W	5.1	5.1
	Total RF (P_{RFDC})	W	10.9	10.9
BB	Radio (inner RX/TX)	W	5.4	5.4
	LTE turbo (outer RX/TX)	W	4.4	4.4
	Processor	W	5.0	5.0
	Total BB (P_{BB})	W	14.8	14.8
DC-DC loss (σ_{DC})		%	6.0	6.0
Cooling loss (σ_{cool})		%	9.0	0.0
Main supply loss (σ_{MS})		%	7.0	7.0
Total per TRX		W	160.8	88.0

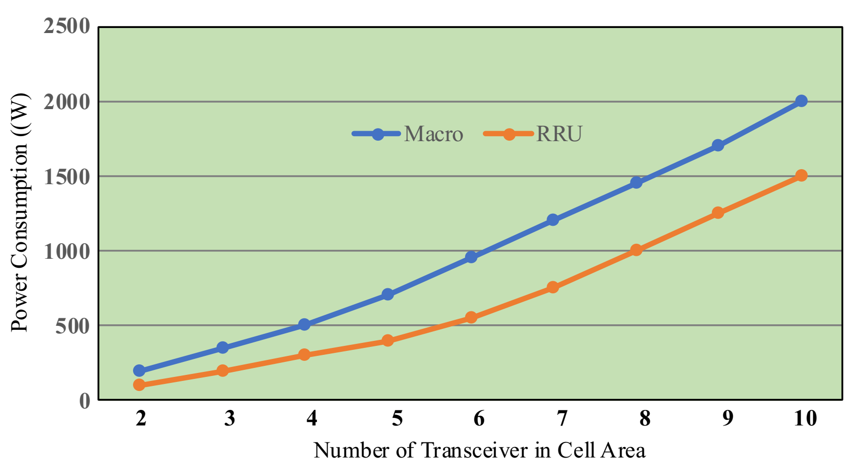

FIGURE 11. The transceiver power consumption for macro-cell and RRU based architectures.

The linear approximation of the power model can be written as:

$$P_{PC} = N_{TRX} \cdot (P_0 + \Delta_p P_{out}), \quad 0 < P_{out} \leq P_{\max} \quad (11)$$

where P_0 is the linear model parameter to represent power consumption at zero RF output power, and Δ_p is the slope of the load dependent power consumption.

In [59], the power consumption of three different BS architectures, macro, micro, and RRH, with realistic assumptions and variables is modeled. They have found that the distributed antenna BS architecture outperforms the macro- and micro-BS architectures. Moreover, the distributed antenna BS architecture compared to the conventional macro-BS architecture shows a 30% reduction in power consumption and a 7-fold increase in energy efficiency.

The capacity of the BBU to antenna unit links is predicted to be significantly greater than the capacity of the antenna unit to UE wireless links. This is due to basic differences in channel performance: interference immunity, low loss, and high bandwidth fibers with dedicated channels against the frequency-selective, time-varying, shared medium of a wireless link. Clearly, the system's limitation in terms of capacity and power consumption comes from the wireless link [67].

As distributed antenna systems become more widely deployed in 5G networks, the path between APs and users will be substantially shorter, resulting in a significant reduction in transmission power. Under this scenario, the BBU becomes the primary source of power consumption [68].

7. CONCLUSIONS AND THE FUTURE WORKS

Eco-friendly, carbon dioxide reduction, and power usage are increasingly major challenges for mobile network providers. Telecom operators are aiming to use the current available base stations for 5G and B5G, as it is increasingly difficult and costly to acquire new site locations or reconstruct the current base stations. To resolve this bottleneck, telecom operators are focusing on moving from a centralized antenna architecture to a distributed antenna architecture, such as the CF-free concept. Saving power consumption, which has a direct relation to the reduction of CO_2 emissions and energy eco-efficiency, should be not only considered in the design of future communication systems but also implemented in the currently available communication systems.

In this paper, we have presented a study on the power consumption of a base station, focused on centralized and distributed antennas that are effective for developing power-saving and energy-efficient mobile networks. We have calculated and compared power consumption for both centralized and distributed antenna architectures by meeting the received power requirement at the end-user terminal. With numerical parameter estimations, our formulation analyses show that power consumption is proportional to the cell size, comparing centralized and distributed antenna architectures. We found that the power consumption of a centralized antenna is higher than that of a distributed antenna. It can be concluded that the distributed antenna system could save power consumption.

The initial results and outcomes of the ongoing work presented in this paper provide valuable insights into the overall impact as well as the relative impacts of the cell size being considered. It also explicitly includes the possibilities of distributed antenna systems for future network energy efficiency and power consumption, as distributed antennas are an approaching technology for improving coverage and reducing power consumption in 5G, B5G, and 6G systems.

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