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Optimized Technique for Unmanned Aerial Vehicle (UAV) Power Harvesting in Cloud-RAN

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ABSTRACT This paper introduces an Optimized Technique for Unmanned Aerial Vehicles (UAVs) Power Harvesting in Cloud-RAN. In full cooperation scenarios, all base station antennas emit energy in all directions, which can lead to higher power consumption and reduced efficiency. Additionally, a power harvesting scheme is implemented to enable UAVs to recharge their batteries during operation, thus extending their endurance. The proposed techniques involve formulating sparse optimization problems and applying reweighted ℓ_1- norm approximation and semidefinite relaxation (SDR) algorithms to solve them iteratively with RRHs simultaneously transmitting information beams to information-receiving terminals and energy beams to active energy-receiving terminals, aiming to optimize power harvesting, reduce total power transmission, and lower the costs of the network. The results demonstrate significant improvements in power harvesting efficiency compared to traditional full cooperation-based approaches. In conclusion, the techniques presented in this paper offer effective solutions for optimizing UAV power harvesting in Cloud-RAN systems. By utilizing sparse beamforming and addressing the problem of full cooperation, these techniques enhance the power harvesting efficiency and sustainability of UAV-based wireless communication networks in Cloud-RAN.

KEYWORDS Unmanned Aerial Vehicles (UAVs), Cloud Radio Access Network (Cloud-RAN), Power Harvesting, Energy Efficiency.

I. INTRODUCTION

The exponential growth in data traffic has brought unmanned aerial vehicle (UAV) communication to the forefront as a promising technology for future wireless networks. Unlike traditional ground transceivers, UAVs rely on limited-capacity batteries, which poses challenges for crucial activities like flight control, data sensing, transmission, and running applications. Typically offering less than 30 minutes of battery life, this limitation restricts their operational duration and makes frequent battery charging impractical.

Energy-harvesting UAVs are vital for extending flight time without significantly increasing the UAV's size or bulk. Recently, wireless-powered UAV networks have emerged, leveraging energy from ambient sources to recharge UAV batteries. The proposed Solar-powered UAVs [1] have gained interest due to their ability to convert solar energy into electrical energy, enabling continuous flight. However, the availability of solar energy varies based on factors like altitude, daylight hours, geographic location, and time of year.

[2] have explored various methods to improve UAV endurance. Solar-powered UAV prototypes have demonstrated continuous flight for up to 28 hours. [3] introduce an energy-neutral design for the Internet of Unmanned Aerial Vehicles (IoUAV) that utilizes wireless power transfer (WPT) through RF signals from charging stations, significantly extending UAVs' operating lifetime. Other studies [4] have focused on UAV-assisted relaying systems that gather energy from ground base stations, considering different fading conditions to analyze the system's performance. UAV power harvesting and wireless-powered UAV networks present promising solutions to address the energy limitations of UAVs and enhance their communication capabilities for future wireless networks.

This paper presents the technical details of the optimized technique, including design considerations, power harvesting, energy management, and downlink transmission. The rest of the paper is structured as follows. The System model is in Section 2. Problem formulation and optimization are in Section 3. Section 4 contains simulation results, and Section 5 is the conclusion.

II. SYSTEM MODEL

TABLE 1 illustrates the symbols used to represent the technique employed in Cloud-RAN. A centralized cloud computing processor (CP) functions as the network's central processing unit, overseeing different forms of collaboration. This includes energy trading cooperatives for Remote Radio Heads (RRHs) based on power balancing demands and the most optimal channel status information. The CP also facilitates real-time energy supply and has access to all IT data, which it shares with the respective RRHs through fronthaul connections. Additionally, it collects energy-related information, such as energy harvesting rates.

TABLE I
LIST OF SYMBOLS

Symbol	Quantity
R	Radio Remote Head (RRH)s
Q	antennas
$\boldsymbol{G_i}$	information receiving terminals (ITs)
$\boldsymbol{U_e}$	single UAVs
$\boldsymbol{\mathcal{R}_b = \{1, \dots, R\}}$	the indexes set for the RRHs
$\boldsymbol{\mathcal{R}_e = \{1, \dots, U_e\}}$	the indexes set the active UAVs
$\boldsymbol{\mathcal{R}_i = \{1, \dots, G_i\}}$	the indexes set for ITs
$\boldsymbol{E_b}$	renewable energy at *b*-th RRH
$\boldsymbol{A_b^{[ahead]}}$	the value of energy bought in the day-ahead market from the *b*-th RRH.
$\boldsymbol{A_b^{[real]}}$	the energy needs to be bought in the real-time market from the *b*-th RRH
$\boldsymbol{S_b}$	the *b*-th RRH with excess energy sold back to the grid
$\boldsymbol{P_b^{[Tx]}}$	total of power transmits
$\boldsymbol{P_b^{[cct]}}$	power of hardware circuit consumption
$\boldsymbol{P_b^{[Total]}}$	total energy consumption on *b*-th RRH
$\boldsymbol{\mu^{[renew]}}$	price of renewable energy per unit
$\boldsymbol{\mu^{[ahead]}}$	daylight energy purchasing price per unit
$\boldsymbol{\mu^{[real]}}$	price of real-time market per unit
$\boldsymbol{\mu^{[sell]}}$	Price of energy sold back to grid
$\boldsymbol{A^{[total]}}$	overall energy cost
$\boldsymbol{v_{rs} \in \mathbb{C}^{Q\times 1}}$	the vector of beamforming
$\boldsymbol{\mathrm{h}_{bm} \in \mathbb{C}^{H\times 1}}$	the vector of channel
$\boldsymbol{b_x \sim \mathbb{CR}(0, \sigma_x^2)}$	the additive white Gaussian noise

A. *ENERGY MANAGEMENT MODEL*

For this proposed technique, it is necessary to install at least one renewable energy collection unit, such as wind turbines or solar panels, at each RRH site. These units generate local renewable energy from natural sources, thereby reducing operational expenses (OPEX) and capital expenditures (CAPEX). However, storage devices for selling excess power back to the CP are not currently integrated into the RRHs. The unequal production of renewable energy can be attributed to the varying locations of RRHs and the reliability of renewable energy harvesting devices.

$$P_b^{[Total]} = P_b^{[Tx]} + P_b^{[cct]} \leq E_b + A_b^{[ahead]} + A_b^{[real]} - S_b \tag{1}$$

Therefore, the total energy cost borne by the RRHs in the Cloud-RAN, denoted as $A^{[total]}$, can be expressed as follows.

$$A^{[total]} = \mu^{[ahead]} \sum_{b\in\mathcal{R}_b} A_b^{[ahead]} + \mu^{[real]} \sum_{b\in\mathcal{R}_b} A_b^{[real]} + \mu^{[renew]} + \sum_{b\in\mathcal{R}_b} E_b + \mu^{[sell]} + \sum_{b\in\mathcal{R}_b} S_b \tag{2}$$

As a result, optimizing resource allocation and energy trading becomes imperative to maximize the network operator's profit.

B. *DOWNLINK TRANSMISSION MODEL*

The combine RRH from the *x*-th IT, $x \in \mathcal{R}_i$ to all RRH as below

$$\boldsymbol{v}_s = [\boldsymbol{v}_{1x}^H, \dots, \boldsymbol{v}_{Rx}^H]^H \in \mathbb{C}^{RQ\times 1} \tag{3}$$

The aggregate beamforming vector from the e-th active UAV to all RRHs is represented as

$$\boldsymbol{w}_s = [\boldsymbol{w}_{1e}^H, \dots, \boldsymbol{w}_{Re}^H]^H \in \mathbb{C}^{RQ\times 1} \tag{4}$$

The channel between the x-th IT and all RRHs is denoted as the aggregate channel, in comparison as below.

$$\boldsymbol{h}_{bx} = [\boldsymbol{h}_{1x}^H, \dots, \boldsymbol{h}_{Rx}^H]^H \in \mathbb{C}^{RQ\times 1} \tag{5}$$

The received signal at the *x*-th IT, where $x \in \mathcal{R}_i$, is expressed as.

$$y_x = \boldsymbol{h}_x^H \boldsymbol{v}_x s_x + \sum_{\substack{j\neq x \\ j\epsilon\mathcal{R}_i}} \boldsymbol{h}_x^H \boldsymbol{v}_j s_j^{[IT]} + \sum_{e\epsilon\mathcal{R}_e} \boldsymbol{h}_x^H \boldsymbol{v}_e s_e^{[UAV]} + b_x, \tag{6}$$

In equation (6), the right-hand side terms correspond to the *x*-th IT's targeted information-carrying signal, the inter-user interference caused by non-desired information beams, the interference originating from energy beams of all active UAVs, and the additive white Gaussian noise. The energy-carrying signals, devoid of information, can be considered as arbitrary random signals. Assuming that

$$\mathbb{E}\left(\left|s_x^{[IT]}\right|^2\right) = \mathbb{E}\left(\left|s_e^{[UAV]}\right|^2\right) = 1 \tag{7}$$

Consequently, the signal-to-interference-plus-noise ratio (SINR) for the x-th IT, where *x*-th IT, $x \in \mathcal{R}_i$ can be formulated as below.

$$SINR_x^{[IT]} = \frac{\left|\boldsymbol{h}_x^H \boldsymbol{v}_x\right|^2}{\sum_{j\neq\mathcal{R}_i\,.j\neq x}\left|\boldsymbol{h}_x^H \boldsymbol{v}_j\right|^2 + \left|\boldsymbol{h}_x^H \boldsymbol{w}_e\right|^2 + \sigma_x^2} \tag{8}$$

The *b*-th RRH fronthaul capacity is given by:

$$C_b^{[fronthaul]} = \sum_{x\in\mathcal{R}_i} \|\boldsymbol{v}_{bx}\|2\|_0\, L_x = \sum_{x\in\mathcal{R}_i} \left\| \|\boldsymbol{v}_{bx}\|_2^2 \right\|_0 L_x, \forall b \in \mathcal{R}_b, \tag{9}$$

In this context, the *x*-th IT is characterized by its achievable data rate in bit/s/Hz, denoted as

$$L_x = log_2\left(1 + SINR_x^{[IT]}\right) \tag{10}$$

It is worth considering that the ℓ_0 −norm in equation (8), when the input values are squared, remains unchanged. The indicator function as,

$$\left\| \|\boldsymbol{v}_{bx}\|_2^2 \right\|_0 \tag{11}$$

The arrangement decisions of individual ITs as outlined below.

$$\left\| \|\boldsymbol{v}_{bx}\|_2^2 \right\|_0 = \begin{cases} 0, & if \|\boldsymbol{v}_{bx}\|_2^2 = 0, \\ 1, & if \|\boldsymbol{v}_{bx}\|_2^2 \neq 0. \end{cases} \tag{12}$$

This implies partial cooperation, where the *b*-th RRH will refrain from participating if the Centralized Cloud Computing Processor (CP) does not transmit data from the *x*-th IT to the *b*-th RRH through the corresponding fronthaul link or in the shared transmission to the *x*-th IT.

The total harvested energy of the *e*-th active UAV, denoted as $e \in \mathcal{R}_e$ can be represented as.

$$\hbar_e^{[UAV]} = \eta\left(\left|\boldsymbol{k}_e^H \boldsymbol{w}_e\right|^2 + \sum_{j\neq\mathcal{R}_e\,.j\neq e}\left|\boldsymbol{k}_e^H \boldsymbol{w}_j\right|^2 + \sum_{x\in\mathcal{R}_i}\left|\boldsymbol{k}_e^H \boldsymbol{v}_x\right|^2\right) \tag{13}$$

The aggregate channel vector,

$$k_e = [k_{1e}^H, \cdots, k_{Re}^H]^H \in \mathbb{C}^{RQ\times 1} \tag{14}$$

represents the channel between all RRHs and the *e*-th active UAV. Here, $0 \leq \eta \leq 1$ denotes the harvested radio frequency (RF) transformation efficiency from energy to electrical energy. It is a constant value that remains the same for all UAVs.

III. PROBLEM FORMULATION AND OPTIMIZATION

A. SPARSE BEAMFORMING TECHNIQUE

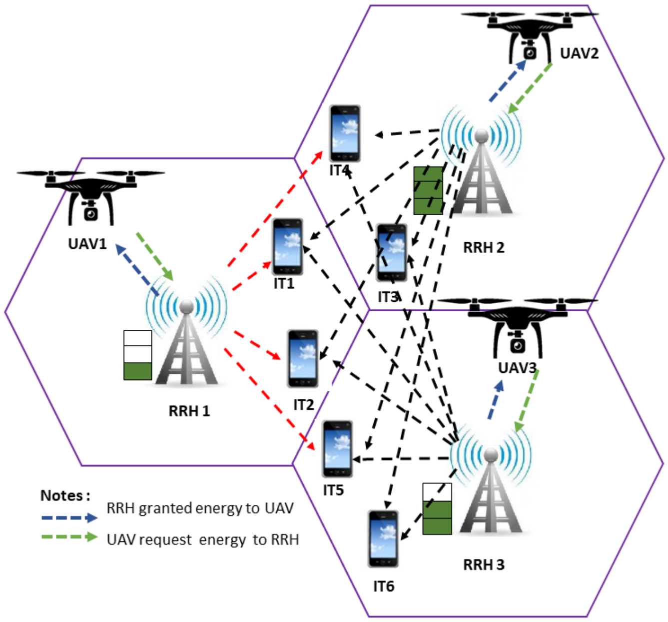

FIGURE 1. The Sparse Beamforming (SB) Technique

The proposed SB technique is depicted in **FIGURE 1**. It aims to minimize the network operator's total energy cost at the RRH fronthaul while considering power shortage and an electricity budget. This is achieved by minimizing a linear combination based on the real-time market of maximum power bought. Under the constraints of maintaining the QoS for ITs, the RRH fronthaul consumption, denoted as $C_b^{[fronthoul]}$ is formulated as

$$C_b^{[fronthoul]} = \sum_{x\in\mathcal{R}_i} \|[\|v_{bx}\|_2^2]\|_0 R_x,\ \forall b \in \mathcal{L} \tag{15}$$

Here R_x represents the rate in bit/s/Hz given by $R_x = \log_2(1+\gamma_x)$ where γ_x corresponds to the SINR requirement for the *x*-th IT. The indicator function (11) indicates the scheduling choices made by individual ITs, and $v_{bx} = 0$ signifies that the *b*-th RRH does not participate in the joint transmission from the *x*-th IT due to power restrictions. The CP allows for partial cooperation if the corresponding fronthaul link does not supply data for the *x*-th IT to the *b*-th RRH. The problem optimization can be formulated as.

$$\min_{w_{be}, v_{be}, A_b^{[\text{real}]}} \quad \alpha\wp^{[\text{coop}]} + \zeta \max_{b\in\mathcal{R}_b}\{A_b^{[\text{real}]}\} \tag{16}$$

Constrains:

$$C1: \text{SINR}_x^{[\text{IT}]} \geq \gamma_x, \quad \forall x \in \mathcal{R}_i$$

$$C2: \hbar_e^{[\text{UAV}]} \geq P_e^{[\text{request}]}, \forall e \in \mathcal{R}_e$$

$$C3: P_b^{[Tx]} \leq E_b + A_b^{[ahead]} + A_b^{[real]} - S_b - P_b^{[cct]}, \quad \forall b \in \mathcal{R}_b$$

$$C4: P_b^{[Tx]} \leq P_b^{[Tmax]}, \ \forall b \in \mathcal{R}_b$$

$$C5: C_b^{[fronthaul]} \leq C_b^{[beam-limit]}, \quad \forall b \in \mathcal{R}_b$$

$$C6: \sum_{b\in\mathcal{R}_b} A_b^{[ahead]} + \sum_{b\in\mathcal{R}_b} A_b^{[real]} \leq P_{CP}^{[max]} - P_{CP}^{[cct]},$$

$$C7: A_b^{[real]} \geq 0, \quad \forall b \in \mathcal{R}_b$$

$$C8: S_b \geq 0, \quad \forall b \in \mathcal{R}_b$$

$$\wp^{[coop]} = \left(\sum_{x\in\mathcal{R}_i} \left\| \|\boldsymbol{w}_{1x}\|_2^2 \right\|_0 + \cdots + \sum_{x\in\mathcal{R}_i} \left\| \|\boldsymbol{w}_{Rx}\|_2^2 \right\| 0\right) + \left(\sum_{e\in\mathcal{R}_e} \left\| \|\boldsymbol{v}_{1e}\|_2^2 \right\|_0 + \cdots + \sum_{e\in\mathcal{R}_e} \left\| \|\boldsymbol{v}_{Re}\|_2^2 \right\|_0\right) \quad (17)$$

In equation (17), we represent the total number of active cooperative links established between the receiving terminals and RRHs. The parameter $\alpha \geq 0$ denotes the maximum power cost incurred in the fronthaul when transmitting data from an active receiving terminal to the serving RRH at the CP. Furthermore, the total power transmitted by the second RRH to its designated receiving terminal is below.

$$P_b^{[Tx]} = \sum_{x\in\mathcal{R}_i} \|\boldsymbol{w}_{bx}\|_2^2 + \cdots + \sum_{e\in\mathcal{R}_e} \|\boldsymbol{v}_{Re}\|_2^2, b \in \mathcal{R}_b \quad (18)$$

The weight factors $\beta \geq 0$ and $\zeta \geq 0$ are introduced to minimize the overall transmit power, represented by

$$\sum_{b\in\mathcal{R}_b} P_b^{[Tx]} \quad (19)$$

The maximum real-time energy purchased from the grid.

$$\max_{b\in\mathcal{R}_b}\{A_b^{[real]}\} \quad (20)$$

Increasing the weighting coefficient places greater emphasis on reducing the corresponding term in the objective function. The minimum SINR requirement for the *x*-th IT is denoted by $\mathfrak{J}_x$.TABLE 2 describe list of constrains for (16).

TABLE 2
LIST OF CONSTRAINS

Constrains	Description
C1	QoS restrictions of set for K_x ITs
C2	$P_e^{[min]}$ reflects the active UAVs with energy transmission in minimum needs
C3	each RRH's overall transmit power is limited by its power budget
C4	overall transmit power shall not be more than the maximum power transmit
C5	specifies the fronthaul link capacity constraints for each RRH
C6	total power of grid provided to RRHs

B. THE SYSTEM AT RRH OF SPARSE BEAMFORMING TECHNIQUE

In **FIGURE 2** below, we present the system configuration at the RRH for the Sparse Beamforming technique. The UAV requests to harvest energy near the RRH within the system. Subsequently, the CP calculates the UAV's location and the corresponding energy demand near the RRH. The nearby RRH authorizes and facilitates the transfer of the required energy from the UAV until the UAV is satisfied and completes the energy harvesting process. It is worth noting that the wireless transmission power of UAVs typically ranges from 100 mW to 10 W, as mentioned by [5]. For the optimization of the proposed techniques, rotary-wing UAV-enabled wireless communication was selected.

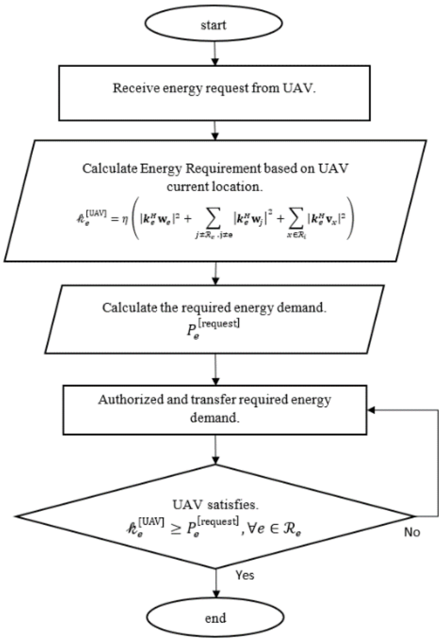

FIGURE 2. The System at RRH for Sparse Beamforming Technique

C. THE SYSTEM AT UAV OF SPARSE BEAMFORMING TECHNIQUE

In **FIGURE 3**, we observe the system configuration at the UAV employing the SB technique 1. When the energy level of the UAV depletes, it requests energy from the nearest RRH within the system. The UAV waits for the response of the nearest RRH, which permits energy harvesting until the UAV's energy requirements are satisfied.

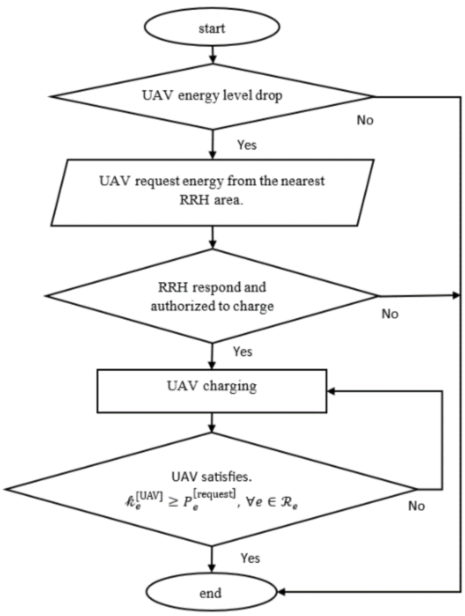

FIGURE 3. The System at UAV for Sparse Beamforming Technique

IV. SIMULATION RESULT

The simulation of this model utilizes the parameters in TABLE 3. A Monte Carlo simulation, implemented in MATLAB, is conducted, where each data point is obtained by averaging 200 independent realizations of the channel.

TABLE 3
SIMULATION PARAMETER FOR SPRASE BEAMFORMING TECHNIQUE

Parameter	Value Range
Number of RRHs (*N*)	3
Number of antennas per RRH (*M*)	8
Number of ITs ($\boldsymbol{G_i}$)	6
Number of the UAVs (U_e)	6
The number of renewable energies produced at the *b*-th RRH.	Ex_1=1.5W, Ex_2=0.2W, Ex_3=0.05W
The number of energies bought for the *b*-th RRH from the day-ahead market.	$A_1^{[ahead]} = A_2^{[ahead]} = A_1^{[ahead]} = 0.7\text{W}$
Price of energy bought.	£0.02 per unit energy
from the day-ahead market $\boldsymbol{A_b^{[ahead]}}$	(RM0.11 per unit energy)
Price of energy sold to the grid $\boldsymbol{A_b^{[grid]}}$	£0.07 per unit energy
	(RM0.38 per unit energy)
Price of energy bought.	£0.15 per unit energy
from the real-time market $\boldsymbol{A_b^{[real]}}$	(RM0.82 per unit energy)
Selling price per unit energy to grid, $\boldsymbol{\pi}^{[\mathbf{sell}]}$	£0.05 per unit energy
	(RM0.27 per unit energy)
Distance between two adjacent RRHs (D_{RRH})	500 m
UAVs altitude, H	120 m
The channel bandwidth wide.	20 MHz
Circuit power consumption at the CP $\left(\boldsymbol{P_{CP}^{[\text{circuit}]}}\right)$	40dBm
Maximum power provision at the CP $\left(\boldsymbol{P_{CP}^{[\mathbf{max}]}}\right)$	50dBm
The *b*-th RRH circuit's power consumption $\left(\boldsymbol{P_b^{[\text{circuit}]}}\right)$	30dBm
Allowance for maximum transmission power $\left(\boldsymbol{P_b^{[\mathbf{Tmax}]}}\right)$	46dBm
Requested energy required by the active UAVs $\left(\boldsymbol{P_e^{[\mathbf{Request}]}}\right)$	20dBm
Fronthaul capacity limit at the *b*-th RRH $\boldsymbol{C_b^{[\mathbf{beam-limit}]}}$	40bits/s/Hz
Efficiency ratio ($\boldsymbol{\eta}$) for energy harvested	0.5
Weight factor of hexagonal covering area ($\mathfrak{I}_{bm}$)	0.2
Array antenna gain (*Ga*)	15dBi
Noise power spectral density	-174 dBm/Hz
Receiving terminals Noise figure	5dB
Path loss model over *d* km distance	125.2+36.3log10(*d*)
Angular offset standard deviation (*s*)	2°
Log-normal shadowing standard deviation (*ss*)	8dB
The distance between two neighbouring antenna components (*d*)	$\lambda/2$
The simulation results are averaged over several independent channel realizations.	200

FIGURE 4 shows a scenario where three neighboring RRHs are situated 500 meters apart. The network consists of six ITs and six UAVs randomly distributed without considering the weight factor of the energy serving area for the UAVs.

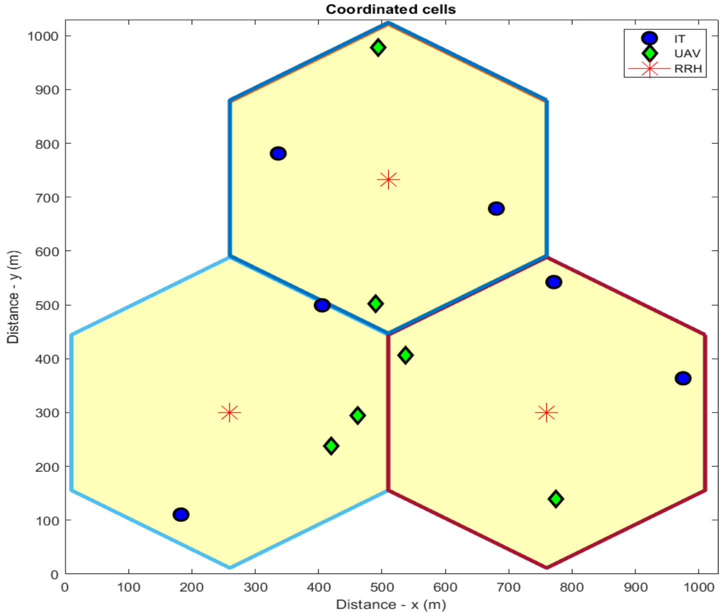

FIGURE 4. The A Multi-user Downlink without Iterative Authorization Algorithm Cloud-RAN Simulation Topology

A. THE IMPACT OF PARTIAL COOPERATION IN CLOUD-RAN WITH UAV

FIGURE 5 below presents a comparison between the total transmit power of full cooperation and sparse beamforming (SB) technique. From the simulation result, average total transmitted power for Full Cooperation is 41.37 dBm (13.7W) and Sparse Beamforming Technique is 35.53 dBm (3.6W) at 20dB SINR. In the range of 0 to 25 dB SINR, the sparse beamforming technique demonstrates superior performance compared to full cooperation, as indicated by the average total transmit power. As the SINR increases, the average total transmit power also increases. However, the full cooperation approach exhibits higher total transmitted power compared to other sparse beamforming techniques, which operate at a limited SINR of 20 dB due to fronthaul capacity constraints. The sparse beamforming technique achieves lower total transmit power, meets higher SINR targets, and effectively manages total transmit power for selected UAVs.

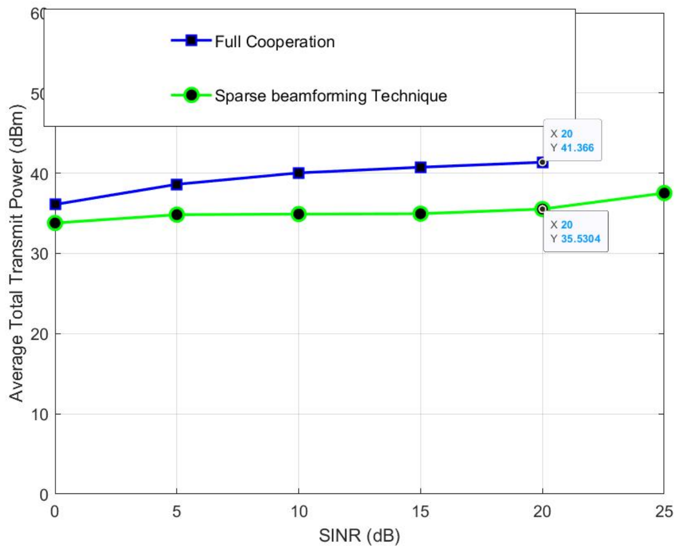

FIGURE 5. The System at UAV for Sparse Beamforming Technique

FIGURE 6. depicts RRH 1's clustering behavior using the sparse beamforming technique, targeting a SINR of 20 dB. Only the cooperative links between RRH 1 and the 1st and 4th ITs are maintained with the proposed Sparse beamforming technique. However, RRH 1's capability to transmit power to the remaining ITs is almost reduced due to its constrained power budget and fronthaul capacity.

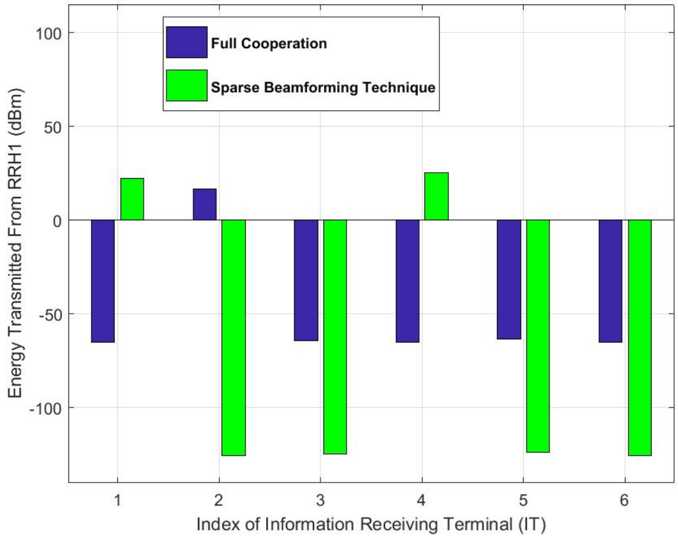

FIGURE 6. The Clustering Behavior of RRH 1 Aims for a Target SINR At γ_x=20 Db

In **FIGURE 7**, the clustering behavior of RRH 2 is illustrated for the sparse beamforming technique, targeting a SINR of 20dB. The cooperative links are maintained for the proposed parse beamforming technique, specifically for the 2nd IT and the 3rd IT. However, RRH 2's capacity to transmit power to the remaining ITs is reduced to zero due to its limited power budget and fronthaul capacity restriction.

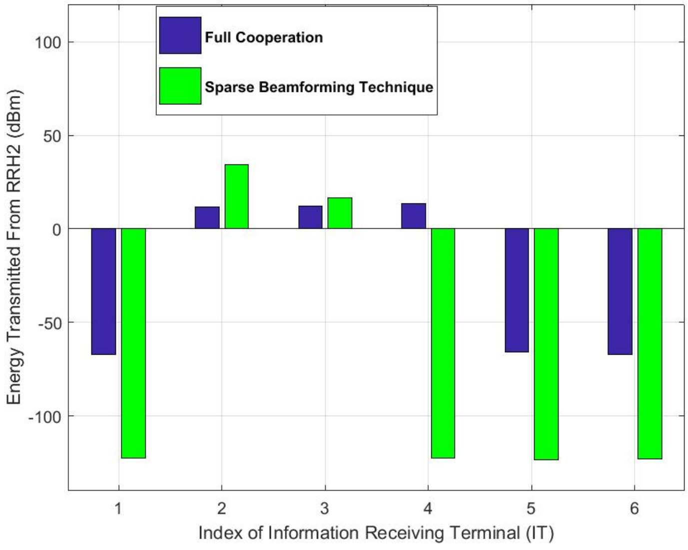

FIGURE 7. The Clustering Behavior of RRH 2 Aims for a Target SINR At γ_x=20 Db

At the 20dB target SINR, **FIGURE 8** demonstrates RRH 3's clustering behavior using sparse beamforming. The proposed SB techniques maintain cooperative links with the 5th and 6th ITs. However, due to a limited power budget and fronthaul capacity, RRH 3's capacity to transmit power to the remaining ITs is nearly eliminated.

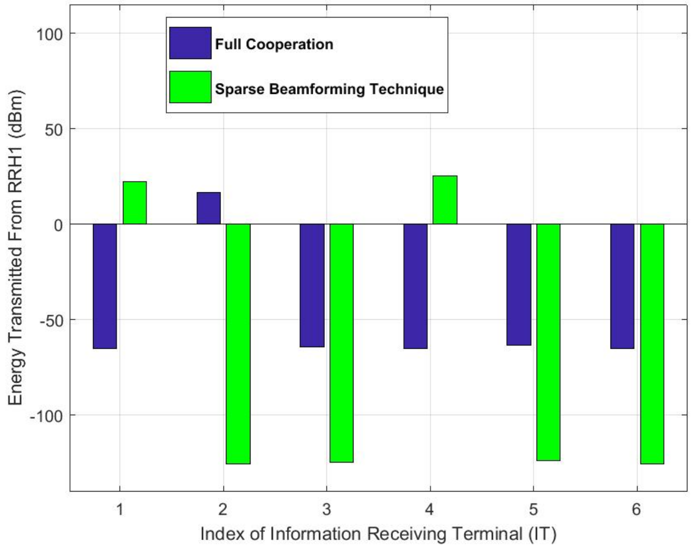

FIGURE 8. The Clustering Behavior of RRH 3 Aims for a Target SINR At γ_x=20dB

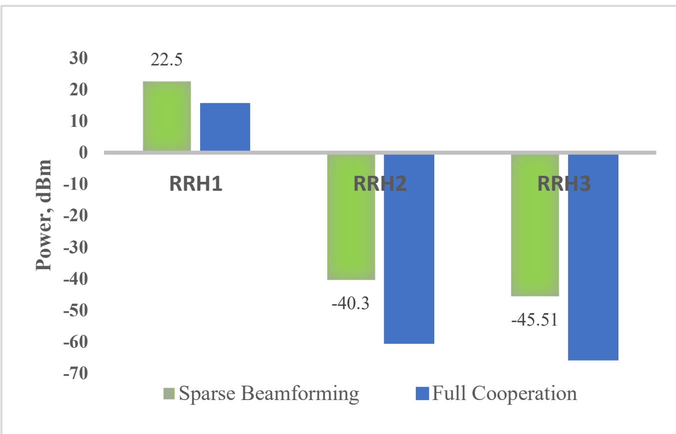

FIGURE 9(a). The Energy Harvested at UAV1 from RRHs for Sparse Beamforming Technique

B. THE ENERGY HARVERSTED AT UAV FROM RRHs

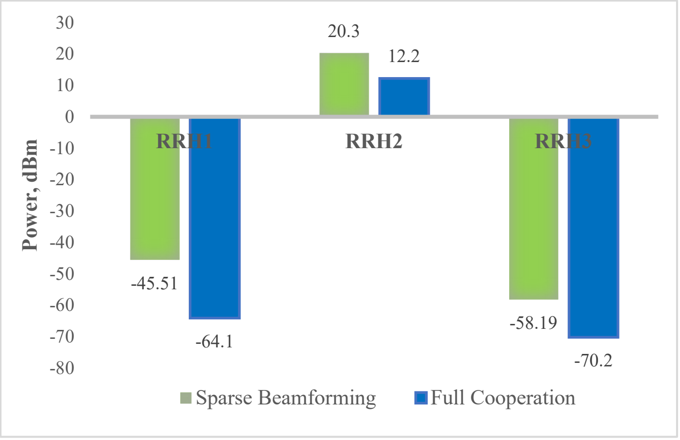

FIGURE 9(b). The Energy Harvested at UAV2 from RRHs for Sparse Beamforming Technique

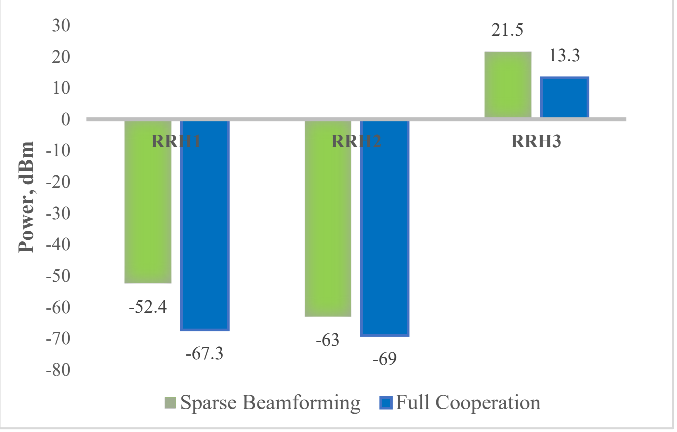

FIGURE 9(c). The Energy Harvested at UAV3 from RRHs for Sparse Beamforming Technique

In **FIGURE 9(a-c)**, the energy obtained by UAV 1, UAV 2, and UAV 3 from all the RRHs in the Cloud-RAN is depicted. UAV 1 harvested 22.5 dBm (177.83 mW) at RRH 1, UAV 2 harvested 20.3 dBm (107.15 mW) at RRH 2, and UAV 3 harvested 21.5 dBm (141.25 mW) at RRH 3 for SB Technique. Additionally, it's shown that only one RRH serves a single UAV at a time in propose SB Technique, while the other RRHs release their cooperative links by gradually reducing their transmit power to close to zero. The RRHs only grant the request when the UAV is near the respective RRH for harvesting energy in proposed SB Technique.

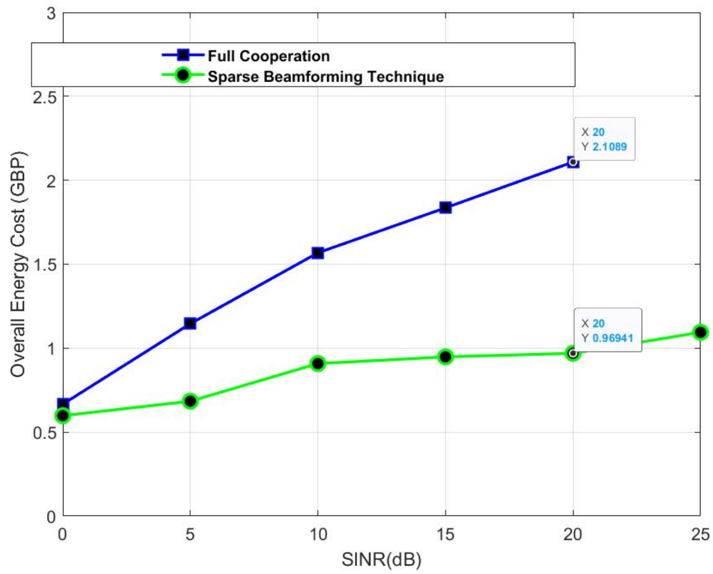

FIGURE 10 The Overall Energy Cost vs SINR $\gamma_1 = 25$ dB

With an average SINR of 25 dB, the sparse beamforming technique (γ_1) achieves the highest SINR targets, resulting in the lowest average total energy cost among all techniques shown in Figure10. The total energy cost for SB Techniques is £1.1 (RM6.25), which is lower than the full cooperation cost of £2.11 (RM12.50). Thus, the excellent sparse beamforming technique leads to significant savings in total energy costs proved in proposed SB Technique.

V. CONCLUSION

Numerical results confirm the superiority of the proposed sparse beamforming technique over full cooperation in cloud-RAN, particularly regarding total transmit power. The simulation outcomes demonstrate that sparse beamforming outperforms full cooperation in terms of achieving the lowest total power transmitted. It achieves higher SINR targets and preserves total transmit power for selected UAVs. Additionally, the clustering behavior analysis reveals that only cooperative links between specific RRHs are retained, while other RRHs' ability to transmit power to the ITs is reduced due to limited power budgets and fronthaul capacity. Overall, sparse beamforming techniques result in the lowest total energy cost and surpass full cooperation in meeting SINR requirements at low to medium SINR demands.

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