UAV-assisted Wireless Powered Relay Networks with Cyclical NOMA-TDMA

Zoran Hadzi-Velkov, Senior Member, IEEE, Slavche Pejoski, Member, IEEE, Nikola Zlatanov, Member, IEEE, and Robert Schober, Fellow, IEEE

Abstract—We optimize the performance of an unmanned aerial vehicle (UAV)-assisted wireless powered relay network (WPRN), where the UAV is used as a radio-frequency (RF) power transmitter and as a communication relay between energy harvesting users (EHUs) and a base station (BS). The EHUs are assigned to radial service sectors, centered around the base station (BS), and employ a combination of non-orthogonal multiple access (NOMA) and time-division multiple access (TDMA), referred to as cyclical NOMA-TDMA, for multiple access. For performance optimization, maximization of the sum rate in all service sectors and maximization of the minimal sum rate per service sector are considered, and the optimal radii of the UAV’s circular trajectory and the optimal allocation of the UAV’s transmit power across the service sectors are determined.

Index Terms—Wireless power transfer, relaying, multiple access techniques, unmanned aerial vehicles.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) can be deployed as mobile relays to assist the wireless communication between a base station (BS) and its users [1]. When the users are far away from the BS or blocked by obstacles (e.g., mountains or buildings), UAV relaying can improve the throughput and extend the range of communication by exploiting line-of-sight (LOS) air-to-ground links [2]-[4]. Assuming a UAV relay flies on a circular trajectory, the authors of [3] and [4] maximize the network energy efficiency and minimize the network outage probability, respectively.

Apart from relaying, UAVs can also facilitate wireless power transfer (WPT). Since WPT is effective only over short distances, a radio frequency (RF) power beacon can be mounted on a mobile UAV and deployed close to RF energy harvesting (EH) devices, thus extending their operational distance from the BS [5]-[7]. For this case, the authors in [5] maximize the total received energy for an arbitrary distribution of the EH users (EHUs), whereas the authors in [6] maximize the minimum received energy for linear alignment of the EHUs. The sum rate is maximized in [7] where the EHUs send information to the UAV in the uplink (UL) and the UAV charges the EHUs wirelessly in the downlink (DL).

The efficient and fair sharing of the system resources (such as power, bandwidth, and time) is one of the main design issues for UAV-assisted communication systems. Time division multiple access (TDMA) is typically used to schedule the information and energy transfer between UAVs and users, where the time allocation among the users is optimized [7], [8]. If rotary-wing UAVs are employed, the uplink throughput is maximized when the UAV successively hovers at a finite number of hovering points [7]. Compared to rotary-wing UAVs of similar size, fixed-wing UAVs consume less aerodynamic power although they are unable to hover [4].

For fixed-wing UAVs acting as mobile relays, fair yet simple user scheduling is challenging when the users are scattered around the BS. In this paper, we consider a wireless powered relay network (WPRN) consisting of multiple ground EHUs, a ground BS, and a fixed-wing UAV carrying a power beacon and a relay. We propose a novel system design for WPRNs where the UAV follows a circular trajectory and divides the area around the BS into multiple service sectors of equal size receiving equal service times. The system may employ cyclical TDMA to provide periodic access to the ground EHUs as the UAV flies periodically in their vicinity [8]. For an improved spectral efficiency, non-orthogonal multiple access (NOMA) can be combined with TDMA [9], [10], which results in cyclical NOMA-TDMA allowing multiple ground EHUs to simultaneously communicate with the UAV over the same time-frequency resources. For this system, we develop novel fairness-aware resource allocation schemes.

II. SYSTEM MODEL

We consider a WPRN that consists of a BS, N ground-based EHUs, and a decode-and-forward (DF) relay/RF power beacon mounted on a UAV. All nodes operate in the half-duplex mode over the same frequency band. Each node is equipped with a single antenna. Each EHU has a rechargeable battery, modeled as an energy queue with infinite storage capacity, where it stores the RF energy harvested from the UAV. The UAV powers the EHUs wirelessly so that they can transmit their information back to the UAV, which then relays the information to the BS.
A. Service Sectors

The WPRN employs hybrid TDMA/NOMA for efficient resource sharing. Specifically, each TDMA frame is divided into $K$ time slots of equal duration, and each time slot is subdivided into two intervals: an UL interval and a DL interval. As specified below, the UL interval is used by the EHUs to simultaneously access the channel to the UAV by employing NOMA. The DL interval is used by the UAV to relay the information received in the preceding UL interval from the EHUs to the BS, while simultaneously broadcasting RF energy to the EHUs. The duration of each TDMA frame is $T$, and the duration of each time slot is $\Delta T$, i.e., $\Delta T = T/K$. The durations of the UL and DL intervals of each time slot are equal to $\Delta T/2$.

As depicted in Fig. 1, we assume that the BS is located at the origin $(0,0,0)$ of a 3D-cylindrical coordinate system $(r, \phi, z)$, whereas the EHUs are located at arbitrary coordinates on the ground. The UAV flies at altitude $h$ on a circular trajectory centered at the BS with radius $r_0$ and a revolution period $T$, thus providing the $K$ service sectors with equal service times, $\Delta T$. Specifically, the UAV trajectory is divided into $K$ arcs with equal central angles $\Delta \phi$ given by

$$\Delta \phi = \frac{2\pi}{K}, \quad (1)$$

and the $k$th service sector is defined as the region on the ground that spans the angles between $\phi_k - \Delta \phi/2$ and $\phi_k + \Delta \phi/2$, where

$$\phi_k = \frac{2\pi(k-1)}{K}, \quad 1 \leq k \leq K. \quad (2)$$

During the $k$th time slot of a TDMA frame, as the UAV traverses along the $k$th arc, it relays the information from the EHUs located in the $k$th service sector. We assume the $k$th service sector contains $N_k$ EHUs, denoted by $\text{EHU}_{n,k}^{(1)}, \text{EHU}_{n,k}^{(2)}, \ldots, \text{EHU}_{N_k,k}^{(k)}$, located at respective coordinates, $(r_1,k,\phi_1,k,0)$, $(r_2,k,\phi_2,k,0), \ldots, (r_{N_k},k,\phi_{N_k},k,0)$, which satisfy

$$\phi_k - \frac{\Delta \phi}{2} < \phi_{n,k} \leq \phi_k + \frac{\Delta \phi}{2}, \quad 1 \leq n \leq N_k, \quad (3)$$

where $N = \sum_{k=1}^{K} N_k$ holds.

At time $t$, the UAV coordinates are $(r_0, \phi_0(t), h)$, where $0 \leq \phi_0(t) \leq 2\pi$ and $0 \leq t \leq T$. During the $k$th time slot, the UAV traverses the angles $\phi_k - \Delta \phi/2 < \phi_0(t) \leq \phi_k$ in the UL interval, and the angles $\phi_k < \phi_0(t) \leq \phi_k + \Delta \phi/2$ in the DL interval. In the UL interval, the EHUs of the $k$th service sector employ NOMA to transmit their information to the UAV. $\text{EHU}_{n,k}^{(k)}$ transmits information to the UAV relay with a fixed output power, $P_{D,n,k}$. In the DL interval, the UAV jointly decodes the codewords received from the EHUs, re-encodes these codewords as a single new codeword (e.g., by applying superposition coding), and forwards this codeword to the BS with fixed output power $P_{B}$. Simultaneously, during the DL interval, all EHUs harvest the RF energy of the UAV’s transmit signal.

B. Channel Model

At an arbitrary time instant $t$, the distance between the UAV and $\text{EHU}_{n,k}^{(k)}$ is given by

$$d_{n,k}(t) = \sqrt{r_0^2 + r_{n,k}^2 + h^2 - 2r_0 r_{n,k} \cos(\phi_0(t) - \phi_{n,k})}, \quad (4)$$

which only depends on the UAV position, i.e., $d_{n,k}(t) = d_{n,k}(\phi_0(t))$. When the UAV flies within the $k$th service sector, its distance to $\text{EHU}_{n,k}^{(k)}$ satisfies

$$D_{n,k}^{\min} \leq d_{n,k}(t) \leq D_{n,k}^{\max}, \quad (5)$$

where

$$D_{n,k}^{\min} = \sqrt{(r_{n,k} - r_0)^2 + h^2}, \quad (6)$$

and

$$D_{n,k}^{\max} = \sqrt{r_0^2 + r_{n,k}^2 + h^2 - 2r_0 r_{n,k} \cos(2\pi/K)}. \quad (7)$$

We assume that the air-to-ground channel is modeled by the so-called “probabilistic LoS model” [11], where the presence and absence of the line-of-sight (LoS) link is modeled as a random variable. Specifically, the channel gain between the UAV and $\text{EHU}_{n,k}^{(k)}, x_{n,k}(t)$, is given by

$$x_{n,k}(t) = \begin{cases} \beta_0 d_{n,k}^{\alpha}(t), & \text{LOS link} \\ \kappa \beta_0 d_{n,k}^{\alpha}(t), & \text{non-LOS link} \end{cases}, \quad (8)$$

where $\alpha$ is the path-loss exponent, $\beta_0$ is the channel gain at a reference distance of 1 m, and $\kappa$ is the additional attenuation factor when there is no LoS ($\kappa < 1$). The LoS probability, $Q_{n,k}(t)$, can be modeled by [11, Eq. (5)]

$$Q_{n,k}(t) = \frac{1}{1 + C \exp \left(-D \left(\frac{\arcsin \left(\frac{h}{d_{n,k}(t)}\right)}{\pi} - C\right)\right)}, \quad (9)$$

where $C$ and $D$ are parameters that depend on the propagation environment. Due to (4), $Q_{n,k}(t) = Q_{n,k}(\phi_0(t))$, i.e., $Q_{n,k}(t)$ depends only on the UAV position.

Since $\text{EHU}_{n,k}^{(k)}$ transmits information only during the $k$th time slot of each TDMA frame (i.e., while the UAV traverses the $k$th service sector), its transmission rate can be adjusted to the channel gain $x_{n,k}(t)$ so as to avoid outages.
Specifically, we fix the transmission rate of EHU\(_{(k)}\) in order to transmit reliably for the maximum distance, \(D_{\text{max}}^{n,k}\) in the absence of a LoS link, which corresponds to channel gain \(X_{n,k} = \kappa \beta_0 (D_{\text{max}}^{n,k})^{-\gamma}\), i.e.,

\[
X_{n,k} = \frac{\kappa \beta_0}{(r_0^2 + r_{n,k}^2 + h^2 - 2r_0 r_{n,k} \cos(2\pi/K))^{\alpha/2}}. \tag{10}
\]

Due to the circular trajectory of the UAV, the distance between the UAV and the BS is constant and given by \(D_0 = \sqrt{r_0^2 + h^2}\). In order to avoid outages also for the UAV-BS link, the transmission rate is adjusted to the case when the LoS is absent, i.e., to channel gain

\[
X_0 = \frac{\kappa \beta_0}{(r_0^2 + h^2)^{\alpha/2}}. \tag{11}
\]

C. Average Harvested Power

Since the EHUs harvest RF energy during the DL interval of each time slot, at time \(t\), the amount of harvested power by EHU\(_{(k)}\), denoted by \(P_{Hn,k}(t)\), is given by

\[
P_{Hn,k}(t) = \eta_{n,k} P_0 x_{n,k}(t), \quad \text{if } t \text{ belongs to a DL interval}
\]

\[
P_{Hn,k}(t) = 0, \quad \text{otherwise}, \tag{12}
\]

where \(\eta_{n,k}\) is the energy conversion efficiency of EHU\(_{(k)}\) (\(0 < \eta_{n,k} < 1\)) and \(x_{n,k}(t)\) is given by (8). Since \(d_{n,k}(t)\) is a time-periodic function, the average power harvested by the \(k\)th EHU, denoted by \(\bar{P}_{Hn,k}\), is obtained by averaging \(P_{Hn,k}(t)\) over a single period \(T\), i.e., \(\bar{P}_{Hn,k} = E[P_{Hn,k}(t)]\), where \(E[\cdot]\) denotes expectation. Equivalently, \(\bar{P}_{Hn,k}\) can be obtained by averaging (12) over the uniformly distributed angle \(\phi_0\) (\(0 \leq \phi_0 \leq 2\pi\)), yielding

\[
\bar{P}_{Hn,k} = \eta_{n,k} \sum_{i=1}^{K} P_0 G_i(r_0, r_{n,k}, \phi_{n,k}). \tag{13}
\]

where

\[
G_i(r_0, r_{n,k}, \phi_{n,k}) = \frac{\beta_0}{2\pi} \int_{\phi_0}^{\phi_0 + \Delta \phi/2} Q_{n,k}(\phi_0) + \kappa (1 - Q_{n,k}(\phi_0)) d\phi_0. \tag{14}
\]

Here, \(\Delta \phi\), \(\phi_0\), \(d_{n,k}(\phi_0)\), and \(Q_{n,k}(\phi_0)\) are given by (1), (2), (4), and (9), respectively. \(G_i(r_0, r_{n,k}, \phi_{n,k})\) denotes the average gain of the channel between EHU\(_{(k)}\) and the UAV while it traverses the \(i\)th sector. Its value can be determined numerically for a given set of values \((r_0, r_{n,k}, \phi_{n,k})\).

During the UL interval of the \(k\)th slot, EHU\(_{(k)}\) transmits information at fixed output power, \(P_{Dn,k}\), by spending all its energy harvested during the previous \(K\) time slots, \(\bar{P}_{Hn,k}T\). Since the duration of the UL interval is equal to \(T/(2K)\), the value of \(P_{Dn,k}\) is determined by

\[
P_{Dn,k} = \frac{T}{2K} = \bar{P}_{Hn,k}T. \tag{15}
\]

\footnote{As \(K\) increases, the time slot duration \(\Delta T = T/K\) decreases and the EHU spend their harvested energy over a decreasing UL interval to transmit their information. As a result, the output power of each EHU increases linearly in \(K\) (c.f., (15)). In practice, however, \(K\) has to be kept below some threshold because the durations of the DL and UL intervals should be long enough to sustain communication. Specifically, if \(T_{\text{min}}\) is the minimum codeword duration for feasible communication, then \(K \leq \lceil T/(2T_{\text{min}}) \rceil\).}

D. Cyclical NOMA-TDMA

In the UL interval of the \(k\)th time slot of each TDMA frame, \(N_e\) EHU\(_s\) transmit simultaneously data to the UAV by employing NOMA [9]. Based on the received superimposed signal, the UAV decodes the information of the \(N_k\) EHU\(_s\) by employing successive interference cancelation according to a predefined order. To facilitate fairness among the EHU\(_s\) in the \(k\)th sector, the decoding order should be chosen to ensure that EHU\(_s\) with higher channel gains (i.e., EHU\(_s\) closer to the UAV) are decoded earlier (and thus are exposed to more interference) compared to EHU\(_s\) with lower channel gains (i.e., EHU\(_s\) further from the UAV). Thus, the EHU with the highest received power at the UAV will experience interference from all other EHU\(_s\) in the sector, whereas the EHU with the lowest received power at the UAV will not experience any interference. Thus, without loss of generality, we assume the EHU\(_s\) in the \(k\)th sector are annotated in increasing order of their received powers, as follows

\[
P_{D1,k} X_{1,k} \geq \cdots \geq P_{Dn,k} X_{n,k} \geq \cdots \geq P_{DN_k,k} X_{N_k,k}, \tag{16}
\]

such that, at the end of the UL interval of the \(k\)th time slot, the UAV decodes the EHU\(_s\)’s codewords in the following predefined order: EHU\(_1\), EHU\(_2\), ..., EHU\(_i\), ..., EHU\(_{N_k}\). In this case, the rate of EHU\(_0\) is set as [9]

\[
R_{n,k} = \frac{1}{2K} \log_2 \left( 1 + \frac{P_{Dn,k} X_{n,k}}{N_0 + \sum_{i > n} P_{D1,i,k} X_{i,k}} \right), 1 \leq n \leq N_k, \tag{17}
\]

where \(N_0\) is the power of the additive white Gaussian noise at the receiver. The pre-log factor \(1/(2K)\) in (17) accounts for the fraction of time available for transmitting information from each service sector to the BS via the UAV relay. After the joint decoding, the UAV applies superposition coding to re-encode the \(N_k\) codewords into a single superposed codeword, and then transmits it to the BS in the DL interval of the \(k\)th time slot. The rate of the superimposed codeword is equal to the sum rate of the EHU\(_s\) in the \(k\)th sector, and given by

\[
R_{k}^{UL} = \sum_{n=1}^{N_k} R_{n,k} = \frac{1}{2K} \log_2 \left( 1 + \sum_{n=1}^{N_k} \frac{P_{Dn,k} X_{n,k}}{N_0} \right) = \frac{1}{2K} \log_2 \left( 1 + \sum_{i=1}^{K} \frac{P_0 Y_{k,i}(r_0)}{N_0} \right), \tag{18}
\]

where

\[
Y_{k,i}(r_0) = 2K \sum_{n=1}^{N_k} \eta_{n,k} X_{n,k} G_i(r_0, r_{n,k}, \phi_{n,k}), \tag{19}
\]

and \(G_i(\cdot, \cdot, \cdot)\) is defined by (14). Here, \(P_0 Y_{k,i}(r_0)\) in (18) denotes the UAV’s total received power delivered by the EHU\(_s\) in the \(k\)th sector, which originates from the power supplied to the EHU\(_s\) by the UAV while it traverses the \(i\)th sector.

The codeword transmitted from the UAV to the BS can be decoded at the BS if the UAV-BS channel capacity, given by

\[
C_k^{DL} = \frac{1}{2K} \log_2 \left( 1 + \frac{P_{D0} X_{0}}{N_0} \right), \tag{20}
\]

is greater or equal to the sum rate of the EHU\(_s\) in the \(k\)th sector, i.e., \(C_k^{DL} \geq R_{k}^{UL}\), yielding
of some EHUs. Specifically, in order to conserve its transmit power, the UAV transmits at very low powers in those sectors which cannot significantly contribute to the overall sum rate of the system, $R_{\text{sum}}$. This effect is experienced by service sector $k$ if the values of its parameters $Y_{k,i}$, given by (19), are much lower compared to those of the other service sectors. Such sectors are referred to as the "low powered sectors".

B. Maximization of Minimum Sum Rate Per Service Sector

In order to alleviate the above mentioned issue, we now apply an alternative criterion for system performance optimization, which is to maximize the minimum sum rate of all service sectors, given by the following optimization problem:

$$\text{Max}_{r_0, P_{k0}, \forall k} R_{0}$$

subject to

$$C1: \sum_{i=1}^{K} P_{i} Y_{k,i}(r_0) \leq P_{k0} X_0, \quad \forall k,$$

$$C2: \frac{1}{2K} \sum_{k=1}^{K} P_{k0} \leq P_{\text{avg}},$$

where $R_{\text{sum}}$ is given by (22), $C1$ are the $K$ constraints from (21), and $C2$ is due to the UAV's average transmit power constraint. The denominator $2K$ in $C2$ is due to the UAV being silent during the UL interval of each time slot. Given $r_0$, the optimization problem in (23) is convex, because the objective function is concave and the constraints are affine with respect to the optimization variables, $P_{k0}, \forall k$. Thus, for given $r_0$, the solution of (23), $P_{k0}^*(r_0), \forall k$, can be determined by standard convex optimization techniques, such as the interior-point method [12]. Let us denote the value of $R_{\text{sum}}$ at $P_{k0}^*(r_0), \forall k$, by $R_{\text{sum}}^*(r_0)$. The optimal $r_0^*$ is thus determined by

$$r_0^* = \arg\max_{r_0 \geq 0} R_{\text{sum}}^*(r_0). \quad (24)$$

In practice, optimal solution, $(r_0^*, \{P_{k0}^*(r_0^*)\}_{k=1}^{K})$, is obtained by a full search over $r_0 \in [0, r_{\text{max}}]$, where $r_{\text{max}} = \max_{n,k} Y_{n,k}$.

Note that the left hand side (l.h.s) of $C1$ is the total power received by the UAV during the UL interval of the $k$th time slot, which originates from the energy harvested by all EHSUs in the $k$th sector during the previous $K$ time slots. Therefore, the value of the l.h.s. of $C1$ is always positive, and so the solution of (23) satisfies $P_{k0}^* > 0, \forall k$. In some cases, however, the optimal solution may introduce highly uneven UAV powers across the service sectors, resulting in the unfair treatment

3In practice, $P_{\text{avg}}$ is negligible compared to the UAVs aerodynamic power consumption, $P_{\text{aero}}$, and the two powers can be selected independent from each other. Specifically, $P_{\text{aero}}$ of fixed-wing UAVs is minimized at some non-zero speed $v_0^*(r_0)$ [2]. Due to the circular trajectory, a given speed $v_0$ yields a specific value of the revolution period, $T = 2\pi v_0 / \omega$. Thus, we can optimize the performance according to the proposed optimization criteria, while also minimizing $P_{\text{aero}}$ by setting $T^* = 2\pi r_0^*/v_0^*(r_0^*)$. 

IV. NUMERICAL RESULTS

We now compare the performances of the two proposed schemes in terms of their sum rates, $R_{\text{sum}}$, and the fairness of the system, $J$. As a measure of fairness among the service sectors, we apply Jain’s definition of fairness [13], $J = \left( \sum_{k=1}^{K} R_{k}^* \right)^2 / (K \sum_{k=1}^{K} (R_{k}^*)^2)$, where $R_{k}^*$ is given by (18).

The system performance is calculated for three different EHSU distributions (UDs):

(UD1) Each service sector contains a single EHU at a distance of 100 m from the BS, i.e., $(r_{1,k}, \phi_{1,k}) = (100 m, 2\pi k/K \text{ rad})$, $\forall k$;

(UD2) Half of the sectors contain one EHU, each at a distance of 100 m from the BS (i.e., $r_{1,2k} = 100 m, \forall k$), and the other half contain one EHU each at a distance of 120 m from the BS (i.e., $r_{1,2k-1} = 120 m, \forall k$);

(UD3) Half of the sectors contain one EHU each at a distance of 100 m from the BS (i.e., $r_{1,2k-1} = 100 m, \forall k$), and the other half contain three EHUs each at a distance of 100 m from the BS (i.e., $r_{1,2k-1} = r_{2,2k}, r_{3,2k} = 100 m, \forall k$);

(UD4) Each service sector contains a single EHU with random distance uniformly distributed in the interval [100 m, 120 m] from the BS. $R_{\text{sum}}$ and $J$ are averaged over multiple realizations of EHSUs’ locations.

As a benchmark, we present the performance of the proposed system for equal allocation of the UAV’s transmit power across all sectors (i.e., $P_{k0} = 2P_{\text{avg}}, \forall k$). The system parameters are set as: $\eta_h, k = 0.5, \forall k, N_0 = 10^{-12}$ Watts, $h = 10 m$, and $K = 10$. For our simulations, we assumed all channels
are LoS and affected only by free-space path loss, thus setting $\beta_0 = 10^{-3}$, $\kappa = 1$, and $\alpha = 2$. For each of the four UDs, Figs. 2 and 3 depict the system performance metrics ($R_{\text{sum}}$ and $J$) as functions of the UAV’s average transmit power ($P_{\text{avg}}$) for the three considered resource allocations, referred to as “max sum-rate”, “max min-rate”, and “benchmark”.

Since UD3 employs a higher number of EHUs, all three schemes attain higher sum rates than for UD1, UD2, and UD4. For UD1 and UD3, $r_0^* = 100$ m is optimal for all three schemes, since the UAV should naturally fly above the circle on which all EHUs are located. For UD1, the performances of the three schemes coincide for all $P_{\text{avg}}$, because the solutions of both (23) and (25) yield equal power allocation (i.e., $P_k^0 = 2P_{\text{avg}}, \forall k$). For UD2, $r_0^* = 100$ m is optimal for the “max sum-rate” and the benchmark scheme, whereas $r_0^* = 110$ m is optimal for the “max min-rate” scheme. Actually, the “max min-rate” scheme takes fairness into account, thus placing the UAV on an intermediate radius between 100 m and 120 m, whereas the “max sum-rate” scheme does not account for system fairness, but rather greedily maximizes the sum rate by instigating “low powered regime” in those sectors whose EHUs are at a distance of 120 m from the BS. Naturally, for UD4, both performance metrics lie between those of UD1 and UD2. For UD4, the three designs yield a similar performance, although, for each set of random EHU locations, (23) and (25) lead to an unequal allocation of the BS transmit power.

Focusing separately on either UD2, UD3, or UD4, we notice that $R_{\text{sum}}$ of the “max min-rate” scheme are slightly lower than those of the other two schemes, because this scheme maximizes $J$ rather than $R_{\text{sum}}$. Noticeably, the “max min-rate” scheme actually guarantees ideal fairness ($J = 1$) for the four considered UDs. The fairness of the “max sum-rate” scheme for UD2 is significantly lower than those of the other two schemes for UD2, because half of the sectors are “low powered sectors” with minor contribution to $R_{\text{sum}}$. On the other hand, the “max sum-rate” scheme for UD3 and UD4 does not cause “low powered sectors”, which, compared to their corresponding “max min-rate” schemes, results in slightly higher $R_{\text{sum}}$, but slightly lower (than the ideal) fairness.

V. CONCLUSIONS

We have proposed a novel access method for UAV-assisted WPRNs, where the UAV provides cyclic access to the service sectors around the BS. We have maximized the sum rate and the minimal rate per sector by optimizing the UAV’s trajectory radius and the power allocation across the service sectors. When the distribution of the EHUs’ distances from the BS is uneven, at the cost of minor degradation of the network throughput, the “max min-rate” design offers a much higher level of fairness than the “max sum-rate” design.

REFERENCES