Maximizing Network Connectivity for UAV Communications via Reconfigurable Intelligent Surfaces

MMohammed S.AAlAAbidd, Mohammad Javad-Kalbasii, anddShhhrokhlValaesee

Depleepartntenf offelioctrical and Computer Engineering, University of Toronto to Toronto to Toronto to Cartalaada

En Eihaihohohammedshiff @utoronto ca, mohammad, javadkalbasi@nailluttronto to ca, valade @@ecutoronto ca.

Abstract - If tiss anticipated that integrating unmanned aerial vehicles (UAVs) with reconfigurable intelligent surfaces (RISs), resulting in RIS-assisted UAW networks, will offer improved network connectivity against node failures for the beyond 5G networks. In this context, we utilize a RIS to provide path diversity and alternative connectivity ioptions for information flow fromfruseruequipmente(UEUE) (UAVA\bybaddiriggmoreelinks to the network, thereby maximizing its connectivity. This paper employs the algebraic connectivity metric, which is adjusted by the reflected links of the RIS, to formulate the problem of maximizing the network connectivity in two cases. First, we consider formulating the problem for one UE, which is solved optimally using a linear search. Then, we consider the problem of a more general case of nfultiple MEsUWhich has high boghputational complexity proctack lethis problems, we formulate then proble the of maximizing athernic two rks connectivity or assectionity definiterprogrammipgo(SDP)noptin(BZaff)noptoblentithatocaldobe solved refficiently in gridynothial time. In both teases, lour ophoposed solutions of side the object of mbintation between bl/E(s) rande to AVs through the UNISs Ascongesulte in times the reliable shifts of the RISstoshiftect the signals of lither UEs signals appropriate to AVs; thus maximizing/the hetwork/connectivity. Simulation results/are Sonducted to easies a the operformance of other proposed isolutions compared stolthelexisting colutions to the existing solutions

Index Terms—Network connectivity, algebraic connectivity, RIS-assisted WAWcommunications, sgraph liftdown.

I.I.Introduction

UAVs are expected total aveva remarkable blimpact out the ebenomyndayy2026 20th avgflabal market valueeof vals\$5902 bishing the aking paration of drawer citical via beyond 5Gbretwork5G?heOnerbs the uniqueffehrures igfr@AWtassisted EoMmunication is improved network connective tysky lestablishtingifinb-ofestghti(lbisS); diomectionstw(ith S)Esoftle Micanwhild; RISs is a homishige tellificioner that riss integrated i with that is tot égréber i mitdo Vé Aléswork udanecti vityvé ?hetpartikulari vein tietiwork3], that resperiènces deepwfade, that this proitext; R489 cade benleveraged treetprovide path beliversity gaid taltomative porthectivity isolutions after information flew if nor solutions AVs infRdScassistedbWAVonetWbrkso UAVs in RIS-assisted UAV neliber beine concern of UAV communications is that UAV noddse grei pronenter failful@Aducotonseveraltireasons.histidhA& limited aenergymbat dward ufail dree on targeted realismes, insubte easeinoftbettlefieldy, surveillance faysterns, oSuchr JeAM failures

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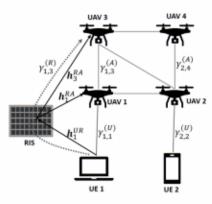


Fig. 1: A typical RISS-assisted/UAV/network with lone RISS2, DIESE and ad UAVAVs.

for aemtöret genbral | | easecofisinheit i picoUEsolahednonesR-ISFItsts shown that a solving this benefit problet Tentitivally is a smooth tationally prohibitive is inceitterequires choff buting whe calgebraic chancetivityn of the resulting network of each ipiesible edge that diffriedts the slifes to that UAV sithrotigh the RISI To tablide this i problems, over a djust the lalge braid it is medicine the problems. thenoniginal tempherbtworkoby, the voundidate edgest between thor/UEs: and https://disklys.evige.thbaRISmiThets, twe. Edfortunate the \problemgof threatiffsizing the lactwork rephase twity dissa sbmi edgfibitei programmingy (SDP); ioptifnization i groble grabat cartybe is object lefficiently late polynomial time. The bdfEscases our proposed solution Stiff the bast combination between the blE(s).xandzthg UiAVsetthroughoutheeRiSt bysstunings its ephase shifts to direct the LEs' esignals to the appropriate LAV suthus solverhizifigitheluciworklyconectivityaeSilmulation results one conducted solassess the defferhence of the prioposed volutions tonipared do the least ting solutions RIS by tuning its phase shifts to direct the UEs' signals to the appropriate UAVs, thukl. n&mstemmModel and Network Connectivitation results are conducted to assess the performance of the proposed solutions compared to the existing solutions.

We consider a RIS-assisted UAV network with a set of UAVs, Hongy RISm and definitiple Net Earth a Corepresent y ground users, sensors, etc. An example of the considered network is shown in Fig. 1. The sets of UAVs and UEs are denoted as We consider a RAS-andsted=UAN 2network with paction by Where, Aris Buscardinality to flath Est that Aller Just sean de UANS are quipped with thingle autempts. Then A diAMst fly dand though oven assigned locations easers fixed Alyangral titude and donned As UEs: with the fusion relation. The locations, of the UANs, WEsternd thetRIS careliass timed to the fixed AWA last time that allAbhannelsufollowl aviquasi-staticuflat-fadingFmodel (aAd/shibs rentain constant avergonel time slots The RIS of installed with a sentain attitude IgEk eti(hg lgg) biothe 2D-location of the BIS((lng, UAVs.) BEtherBiD flocaRbi of class with eUAV, land (ed., We besther@Dhloc ation: hathe ls-fbl ldE, respectively.tiEhthdistarines between the thirth reference characteristic and the sRISt and receive controls RIS and RhES distinish A Mear evel concrete by induction and $d_{x,y}^{RA}$ respectively, be th DBD to chicimatifithde RUSAVs acan, hayebgood & Dnhectivity tof fliEsa-HoweAtr, dills (may, occasional 2D experience flebp fade. To overcontexthis filibbleintand-further/emptove-inchvork

aonhébtivRtySwerproposesterutilizzRASRISido tiheposéhlitkAt/dane dancyted the RES-assisted UAV-spetovorklyAs such, the network becomes and reinesidient lagain AV node, failure g by a providing ip at h diversity and alternatives on activity ionighs between UEsland EAAV.s. TheoR&Scisnequippedpwitheacontrollerrandr Manorable passive reflecting tinits (PRUs) to form a unifolimpassife Stray (MBA)e Each reclumbane the UPA Bus-Msi-PRU Uwith ran regulal spacing lof dheneters/(m); and each row of the diPAnconsisting AddPRkikowithlan equal dipaging tif divers These PRUs can tide indirect links between blfs and UAVs awith tadjustable place shifts.uiThreephase-shift matrixoldfrthenRIS/is modeledpasstbe diagonal gmatrix PRUdi ag (dorm a antiform and sive where $\theta_{LIPA}[0, Each for our mn \{ bf. the M \} Pand has = M_rPRIMe. with$ an Theusuccessfulg communications (abetween abehUEswand the RISArremeasured fusing the distance threshold Ω_o specific of th UE. is I downed to the RISI with distance also bif to the CUEs The Communication substitute on the UEstand ReAMs/RES hift assumed 66 obeurRNer idifferent lithers loth (i.eljaigne abultipteix ing=actions)et6¹ avoideiffterferené6⁴a)mortgethe∂ schediulea)UEs: Therefore, weldssumd that only one ME is transmitting in each time halotato-reduce interference; Gonsidering atherence amoRgShe different edheduled HJEsista the RIS sind the JJAV.s is left for fulling work ected to the RIS with distance $d_u^{(R)}$ if Strice this paper focuses on the one two reconnectivity from data/knk-fayer/viewpointl we abstract the physical-layer factors and consider a model that relies only on the distance between the nodes.\Therefore, \text{Veimodol-only-the-large-scale-fading and} ignore the small scale fading. To quantify the UEs; transmission Cothed LIAVe the drifter fRIS cover using the signal dot noised rated (SNR) o Fore the Stand Hard NR via defined for follows of 31k.

Since this paper focuses on the network connectivity from data link-layer victorint, we, abstract the physical layer factors and consider a model that relies only on the where declared distance between the two hidden only the three declared is a the gransmit power of the luther line that leading transmit power of the luther law high is maintained for the soft all this is less only on the path to symptom of the path to symptom of the path to symptom of the law the l

UAVs hover at high altitudes, thus we reasonably assume that they maintain LoS channel between each other. The path loss between the a-th and the a-th are under the a-th are the a-th are under the a-th a

where $d_{u,a}$ is the distance between the u-th UE and the a-th UAV, p is the transmit power of the u-th UE, which is maintained fixed for stance between the a-th UAV and the Gaussian noise (AWGN) variance and a is the path loss a-th UAV, b-is the carrier frequency, and a is the path loss at the SNK in the between the a-th UAV and the a-th UAV is a-th UAV in the a-th UAV is the stance of the a-th UAV is the first depends on the transmission environment. The SNK in the between the a-th UAV and the a-th UAV is a-all solutions, while a-th UAV is a-all solutions, while a-th UAV is the transmit power of the a-th UAV, which is quantizated fixed for all the UAVs. Note that the SNK weight the off the distributes whether it has a successful sonnection to the corresponding UAV a. In other words, the a-th UAV is a-assumed to be within the transmission range of the UAV is a-assumed to be within the transmission range of the UAV is a-assumed to be within the transmission range of the UAV is a-assumed to be within the transmission range of the UAV is a-assumed to be within the transmission range of the UAVs Similarly, we has successful that UAVa'atlant UAVA'a shall a CAVS that a-cave as successful connection opinion of the UAVa'atlant UAVA'a shall a casuace sequences of the UAVa'atlant UAVA'atlant UAVA'atlant UAVA'atlant UAVA'atlant UAVA'atlant UAVA'atla

space $q_{a}^{(A)}$ $\mathbb{N} \cong S_{b}^{(A)}$ \mathbb{N} , where between the Lights, where P is the incentral Rissischer location of the Lights in the minimum SNR threshold for the communication links between the Lights and the Lights in the Light

Since the RIS is deployed in the higher altitude, the sixtual propagation of the test to RIS limit is (adopted to be a simple yet reasonably accurate LoS channel model [?]. The LoS channel vector between the 15th UE and the RIS is given by u_u^R , φ_u^{UR} , and ψ_u^{UR} are related to the sine and cosine terms of the vertical and horizontal angles of arrival (AoAs) at the RIS [?], and given by φ_u^{UR} ψ_u^{UR} ψ_u

where ϕ_u^{UR} , φ_u^{UR} , and $\overline{\psi}_u^{\mathrm{UR}}$ (area) related to the sine and cosine terms of the vertical and horizontal angles-of-where d_a^{R} Aisatic distance between the RIS and they a the DAY, and $\overline{h_a^{\mathrm{RA}}}$ represents the chiral response component which is an be are related by $y_u - y_R)^2$ and $y_u - y_R - y_R$

where the informationed characteristic Paragraph of the UPCRISCAV this between the useful Daniel the Which Avoldrough the RIS is given by $h_{u,a}^{\text{URA}} = (\mathbf{h}_a^{\text{RA}})^H \Theta \mathbf{h}_u^{\text{UR}}$ [2]. Accordingly, the SNR sof the reflected link between the list UE and the a-th UAV through the RIS can be written as $\gamma_{u,a}^{(R)} = \frac{p|h^{\text{URA}}|^2}{N_0^2}$, e[2]. For successful, confection between UE used UAV a via RIS r, r, r and r are related to the sine is the minimum SNR threshold for the communication links between

white set of the communication links between cosine terms of the Vertical and normalization links between the UEs and the UAVs via the RISS to the a-th UAV [?], and model the considered RIS-assisted UAVs network as an undirected graph $\mathcal{G}(\mathcal{V},\mathcal{E})$, where $\mathcal{V}\sqrt{\#\pi\{v_{1},\hat{w}_{2},(y_{1},...,y_{l})\}}$ is a the set of the network, \mathcal{E}_{R} and \mathcal{E}_{R} and \mathcal{E}_{R} and \mathcal{E}_{R} and \mathcal{E}_{R} are the network,

E Silven the aforegreistheadt dfailledgen dels, the Aneatre ande (Echan Felaforthic multibers Soft vertiers kand tedges time the ghaphErespectivelya-ffheUghAphtl@cimplieshehR [allishgilinks lim the fetwork and beding tional, Accordingly, vt is abbelief to feath nedected alid wice twersa. The edge betweendarth two thodes list cheatodibasod BriSi typical SNR threshold ${}^{(R)}_{a,a} = \frac{p|h^{\text{OTA}}_{a,a}|^2}{N_0}$ [?]. For successful connection between UE u and UAV a via RIS r, $\gamma_{u,a}$ $\geq \gamma_0$, where $\gamma_0^{(RIS)}$ is the minimum SNR th Formen edgether communication that connected when ones $\{a_{Hol}, b_{Hoe}\}$ [EAVs $\{c_{h}, a_{he}, b_{Q}\}$] Syector, where the n-th and m-th elements in a 1 preceived by a 1215 also de 11AV netwespess tively, and east outperwise. The incidence matrix $\mathbf{A} \in \mathbb{R}_{vv}^{v imes t}$ of algraph of isothesmatrix with the lift Ealumnt given by oak, Hence, in undirected graph $\mathcal{G}(\mathcal{V}_0\mathcal{E})$, the Laplacian unarity ${f L}$ isvanald bg | └ reatrix, ewhich isblefined var follows d? ledges in the graph, respectively. The graph G implies that all the links in the network ara hidirectional after, a node v is about to reach node v', and vice versa. The edge between any two nodes is created based on a typical SNR threshold.

B. Network Connectivity D_{v_n} if $v_n = v_m$,

For an edge $(v_n, v_m) = k + E_{if}$ that connects two nodes $\{v_n, v_m\} \in \mathcal{V}$, let \mathbf{a}_k be a vector, where the n-th and m-th elements in \mathbf{a}_k are given by $a_{k,n} = 1$ and $a_{k,m} = 1$ where spectively, and zero) otherwish dides in other codes a tail $\mathbf{A}_n \in i$ Buthe degree of notice G_n is which represente the murible of lathits giving horing indicate, in undirected graph $\mathcal{G}(\mathcal{V}, \mathcal{E})$, then Inepwork reconnectivity, interestic beomeen viry also instead of the reduction of the second smallest eigenvalue [?], measures how well a graph G that has the associated Laplacian matrix L is connected. From its vame, this metric is usually denoted as $\lambda_2(\mathbf{L})$. The motivation of $\lambda_2(\mathbf{L})$ to be used as a network connectivity metric comes from the following two where the entries of \mathbf{L} are given as follows: main reasons [?]. First, $\lambda_2(\mathbf{L})>0$ if and only if $\mathcal G$ is connected, i.e., \mathcal{G} is only the connected graph. It is worth mentioning that, when $\Delta_2(\mathbf{L}) = 0$, the graph is disconnected in which at least one of its vertices is unreachable from any other vertices in the graph. Second, $\lambda_2(\mathbf{L})$ is monotone increasing inhthe edge set, $\{1e2, if GV \neq 4b \in Eh\}$ and $G_{SS} \Rightarrow f(\theta heE_h)$ dend $E_1 d \mathcal{D} E_2$, is thene $\lambda l_2 (\operatorname{Ir}_2) e \ge f \lambda_2 (\operatorname{Ie}_1) v_n$ This him blies $\operatorname{res}_2 (\operatorname{Ie}_2) e$ qualitativefyalleitreserishthe ingomediivity of a graph in the serise that whek large most lightly at the chronic connected with gralph willetlethFoFitrislend;esiriceo\f\fL)siscon goodaheasuigeofvhow Connected the graphy's little grouph Ages at hat exist the twe cia the UEsland then MAVs, Ithes longerette the twork can live without being disconnected directednese Yailures Thus, alicatetwork becomes more resilient. Betsed constant extensions identical terms frquantinative one as unto of the incresors resiliency in this paper. is f and f and f is connected, i.e., f is only one connected graph. It is worth mentioning that when $\lambda_2(\mathbf{L}) = 0$, the graph is disconnected in which at least one of its vertices is unGiven abRIS cassisted dfAM network represented by Segraph $\mathcal{G}(\mathbf{U}, \mathcal{E})$ is what are the optimum ingnihinations detween the UEs and the (UAVs) through the RIS, if 2 order dto Frax imize, \lambde \text{life} of (the) resulting Lipetworks? Essentially, adding theuRES atouthe networkstracksresultningtdoingering graphlyles UEs termultiple UAVsarghich (Lipe is not bonnected dogethered thay galsplrestill be adding his weather native Δp (Lipe is the theoretical distribution of the Library chief a path is the network exclusion of the Library phase shifts, Rishcan shrangy distributed dignals of the Library suffable, the Viscouniax indicates network estimated by the Library suffable, the Viscouniax indicates network estimated with the same his place of similar so and a larger set of edges denoted by \mathcal{E}' with $\mathcal{E}' = \mathcal{E} \cup e^R_{u,a}$, where $e^R_{u,a}$ is the new edge connecting the u-th UE to the a-th UAV through the RIS and $\mathcal{E} \subseteq \mathcal{E}'$. Note that the effect of deploying the RIS appears only in the edge set \mathcal{E} , and not in the node set V [?], [?], [?]. By adding those Interview for motions, the gain can be realized by computing $\lambda_2(\mathbf{L}') \ge \lambda_2(\mathbf{L})$, where $\lambda_2(\mathbf{L}')$ is the resulting Laplacian matrix of a graph $\mathcal{G}'(\mathcal{V}, \mathcal{E}')$.

We consider that in each time slot only one UE can Given a RIS assisted UAV network represented by a graph of the RIS, which directs the UE's signal to only a graph of the RIS, which directs the UE's signal to only a graph of the RIS, what are the optimizing combinations one UAV. In what follows, we consider two different cases, of between the UE's and the UAVs through the RIS in order network configurations to formulate the optimization problem to maximize the transfer of the resulting network? Essentially, adding the RIS to the network may result in connecting multiple UEs to multiple UAVs, which were not connected together. It may also result in adding new alternative options to the UEs if then scheduled UAVs that have indirect communication, links from the Historian the Risks to the network, and by adjusting its white different the second UAXI that have direct links to the UE Our tain is to provide an alternative link to connect the UEvito a single UAV in the set A_0 . As such, the UE does not miss the communication if its Whed Bed UAV has faiffed Now, 187 32 be a binary variable that the down that he is the RIST be confidenced to the death and a share Pat € And gand gunt of the wife. With Eonstdered optimization problem of the cade is commential the control to the a-th UAV through the RIS and $\mathcal{E} \subseteq \mathcal{E}'$. Note that the effect of deploying the RIS appears only in the edge set \mathcal{E} , and pot in the node set V [?], [?], [?]. By adding those new links to the network, the gain can be realized by computing $\lambda_2(\mathbf{L}') \geq \lambda_2(\mathbf{L}')$ where $\lambda_2(\mathbf{L}')$ is the resulting Laplacian matrix of a graph G'(V, E'). $m = \{1, \dots, M\}, (7c)$

We consider that in each time slot only one A_0 , E (74) transmit to the RIS, which directs the UE's signal to only where A_0 in the RIS, which directs the UE's signal to only where A_0 is the very signal of the very configuration of the very signal of

Case 2: Multiple wes and Ohe RIS

Untik 40 dasea Isethat considers dhAVUEhatasea 22 addisean optimization tivari ables that neclects the thribugE that Rifes noits it 40 each { time slots Let | Ath be a set of, reachables UAVs that have indicate dominimate tithe links normatically UAVs that have indicate dominimate tithe links normatically the Rife in its dominimate tithe links normal energy that slots dominimate the links of the links to the UAVAVs that slots adjusted links, to the UAVAVs that slots and variable that its equal-to 10 the RIS is a connected to the artist lattice equal-to 10 the RIS is a connected to the artist lattice links like that its equal-to 10 the artist lattice links is a like of the artist lattice.

Algorithm 1, The Proposed Linear Search for Case 1

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1: Input: One UE u, one RIS, \mathcal{A} and network topology.

2: Construct \mathcal{G}(\mathcal{V}, \mathcal{E}). (7a)

3: Ior a=1,2,\ldots,|\mathcal{A}_0| do

4: Subject to \mathcal{G}(\mathcal{V},\mathcal{E}) of the RIS to the a-th UAV as given in (11), \forall m \in \mathcal{G}(\mathcal{V},\mathcal{E}) \cup \{e_{u,a}^R\} m = \{1,\ldots,M\},

6: Calculate \lambda_2(\mathbf{L}') of a graph \mathcal{G}' (7c)

7: yend {or 1} \forall a \in \mathcal{A}_0,

8: Output: Optimal \lambda_2(\mathbf{L}'). (7d)
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where constraint (??) assures that the RIS directs the signal of the UE to only one UAV Constraint (??) is for zero otherwise. The considered optimization problem in this the RIS phase shift optimization.

Casen2xMultiple UEs and One RIS (8a)

Unlike case 1 that considers one UE, case 2 adds an optimization primite that selects the u-th UE that trade) mits in each time slot. Let \mathcal{A}_0^u be a set of reachable UAVs that have indirect communication links from the u-th WE through the RIS, i.e., $\mathcal{A}_0^u = \{a \in \mathcal{A} \backslash \mathcal{A}_u \mid \gamma_{u,a}^{(R)} \geq \gamma_0^{\mathrm{RIS}}\}$, where \mathcal{A}_0 is the set of UAVs that have direct links to the u-th UE. Let x_u be a binary variable that is equal to 1 if the u-th UE is connected to the RIS, and zero otherwise. Nowelet \mathcal{A}_0^u is an interval of the RIS and the signal of that the life is ransmit to the RIS and the signal of that \mathcal{A}_0^u is reflected from selected to the RIS and the signal of that the is reflected from selected to the RIS and the signal of that the is reflected from selected to the RIS and the signal of that the is reflected from selected to the RIS and the signal of that the is reflected from selected to the RIS and the signal of that the is reflected from selected to the RIS and the signal of that the is reflected from selected to the RIS and the signal of that the is reflected from selected to the RIS and the signal of that the signal of the RIS is reflected from selected to the RIS and the signal of that the signal of the RIS is reflected from selected to the RIS are signal of the RIS in the RIS is reflected from selected to the RIS are signal of the RIS are signal

IV. PROPOSED SOLUTIONS

The section proposes to solve (??) optimally using a linear search over all the possible UAV nodes. Then, the section proposes to solve (??) optimally using a linear search over all the possible UAV nodes. Then, the section formulates (??) as an SDP optimization problem that can be solved efficiently in polynomial time. The process of those proposed solutions are explained in subsections IV-A and $\{\Psi\}$ by respectively: $\{\psi\}$ $\{$

Ah Solutions of Sase (*!) and (??) assure that only one UE can to primary solve (?!) Sweed as the restriction of the restriction of the RIS to that UAV node. In particular, the corresponding phase shift at PRU of the RIS to Vice Proposal Solution as follows [?]

It is computably affordable to optimally solve (??) since it considers offly one UE, however setting (!!!) optimally for the case of multiple UEs is computationally probibitive. Therefore, delin-section proposed (m.selve) (!!!) optima(!) using a linear search over all the possible UAV nodes. Therefore, the computational complexity Polytoposed solution of this case is affordable is into it polytoposed solution of this case is affordable is into it polytoposed solutions.

Algorithm lofthes Proposed Linear Search for Case 1

The penha betweel Earch schedilles solved ??? If work uttiple less can be united by both putting $\lambda_2(\mathbf{L}')$ for a total of $U\sum_{u=1}^U |\mathcal{A}_0^u|$ Laplacian matrices, which dequires huge amount of computation for large letter θ_m graph $\mathcal{C}(LS,\mathcal{E})$, three time United Early we search is high for large network settings. It runs in $\mathcal{O}(4EVV')$ 3)—to (down the $\mathcal{C}_{ab}(D')$ [?]. To overcome such computational intractional intractional interaction finds the feasible UE-RIS-UAV association to Intrinsical $\mathcal{A}(D')$ using SDP solvers [?].

We add a link connecting the u-th UE to the a-th UAV through the RIS if both x_u and y_a^u in (??) are 1. Let z be a vectoring specific ship UE-RIS-UAV candidate associations, in which case $x_u=1$ and $y_a^u=1$, $\forall u\in \mathcal{U}, a\in \mathcal{A}$. Therefore the problem in ???? Wear consider as inaving earself of the optimum UE-RIS-UAV associations, since WAV and the select the optimum UE-RIS-UAV associations and be stimulated as corresponding phase shift at PRU of the RIS to the a-th UAV is calculated as I_{total} and I_{total} are I_{total} as I_{total} and I_{total} as I_{total} as I_{total} and I_{total} as I_{total} and I_{total} as I_{total} as I_{total} as I_{total} as I_{total} and I_{total} as I_{total} and I_{total} as I_{total} and I_{total} and I_{total} and I_{total} as I_{total} and I_{total} as I_{total} and I_{total} and I_{total} are I_{total} and I_{total} and

subject to
$$\mathbf{1}^{T}\mathbf{z} = 1, \mathbf{z} \in \{0, 1\}^{|\mathbf{z}|},$$

where $\mathbf{1} \in \mathbb{R}^{f_{c}} \begin{cases} \mathbf{z}^{l} d_{i} \mathbf{s}^{R} \mathbf{h} = \mathbf{a} \mathbf{l} \cdot \mathbf{b} & \mathbf{n} \in \mathbb{R}^{R} \\ \mathbf{z}^{l} d_{i} \mathbf{s}^{R} \mathbf{h} = \mathbf{a} \mathbf{l} \cdot \mathbf{b} & \mathbf{n} \in \mathbb{R}^{R} \end{cases} + d_{r}(m_{r} - \mathbf{L}) (\mathbf{z}^{\mathrm{UR}})^{\mathrm{RA}} \psi_{\mathbf{c}}^{\mathrm{RA}} + \sum_{l=1}^{|\mathbf{z}|} (\mathbf{z} \mathbf{a}_{l} \mathbf{a}_{l}^{T} \mathbf{l}) \psi^{\mathrm{UR}} \varphi^{\mathrm{UR}} \end{cases}$. (19)

where arginal-incidence vector resulting from adding fink, to the soriginal graph G land Laisistheff a placian inatrix of the original graph G. | Algarity the dimensions of The and L'(2) lie browsed method are summarized in Algorithm 1.

The optimization vector in (12) is the vector \mathbf{z} . The l-th element of \mathbf{z} , denoted by z_l , is either 1 or 0, which corresponds to whether this UE-RIS-UAV association should be chosen or fibr, respectively. The combinatorial objinitization problem with high-complexity. Therefore, $\mathbf{W} = \mathbf{r}_{\mathbf{z}} \mathbf{z} \mathbf{z}$ is NP-than problem with high-complexity. Therefore, $\mathbf{W} = \mathbf{r}_{\mathbf{z}} \mathbf{z} \mathbf{z}$ is NP-than problem with high-complexity. Therefore, $\mathbf{w} = \mathbf{r}_{\mathbf{z}} \mathbf{z} \mathbf{z}$ is the Boolean representation of the $\mathbf{v} = \mathbf{v} \mathbf{z} \mathbf{z}$ is the Boolean representation of the $\mathbf{v} = \mathbf{v} \mathbf{z} \mathbf{z}$ in the $\mathbf{v} = \mathbf{v} \mathbf{z}$ in the $\mathbf{v} = \mathbf$

finds the feasible ject the 12 AV1 association to maximize $\lambda_2(L')$ using SDP solvers [?]. We emphasize that the optimal solution of the relaxed problem we add a link connecting the $y_{\rm e}$ th UE to the $a_{\rm e}$ in (14) is an upper bound for the optimal solution of the th LAV through the RIS if both $x_{\rm w}$ and $y_{\rm e}$ in (?) original problem (12) since it has a larger feasible set. In are 1 Let z be a vector representing the UE-RIS-UAV [?] if was shown that $\lambda_2(L/z_1)$ in (14) is the point-wise candidate associations, in which case $x_{\rm w} = 1$ and $y_{\rm e} = 1$, infimum of a family of linear functions of z, which is a $yu \in U$, $u \in U$,

$$\begin{array}{ll} \max_{\mathbf{z},q} q & \text{(13)} \\ \max_{\mathbf{z},q} \lambda_2(\mathbf{L}'(\mathbf{z})) & \text{(10)} \\ \text{subject to} \ q(\mathbf{I} - \frac{1}{2}\mathbf{I}_0^T) \mathbf{1}_1^T) \preceq \mathbf{L}'(\mathbf{z}) \mathbf{1}_1^T \mathbf{z} \preceq \mathbf{I}'(\mathbf{z}) \mathbf{1}_1^T \mathbf{1}_2^T \mathbf{1}_3^T \mathbf{1}_3^$$

where $\mathbf{1} \in \mathbf{R}^{|\mathbf{z}|}$ is the all-ones vector and

4.5

Proposed Optimal - Case 1

Random - Case 1

Original - Qualify
$$|\mathbf{z}|$$
 $\mathbf{L} + \sum_{l=1}^{|\mathbf{z}|} z_l \mathbf{a}_l \mathbf{a}_l^T$, (111)

where $\mathbf{a}_l^{\mathsf{r}}$ is the incidence vector resulting from adding link l to the original graph \mathcal{G} and \mathbf{L} is the Laplacian matrix of the original graph \mathcal{G} . Clearly the dimension of \mathbf{L} and $\mathbf{L}'(\mathbf{z})$ is $V \times V$.

The optimization vector in (12) is the vector \mathbf{z} . The l-th element of \mathbf{z} denoted by z_l , is either 1 or 0, which corresponds to whether this UE-RIS-UAV association should be chosen or not, respectively. The combinatorial optimization problem in (12) is NP-hard problem with high complexity. Therefore, we relax the constraint on the entries of \mathbf{z} and allow them to take any value in the figer 2al The 1 avagac fractive reconstraint \mathbf{z} constraint \mathbf{z} constraint \mathbf{z} constraint \mathbf{z} constraint \mathbf{z} the problem (12) as where $\mathbf{I} \in \mathbf{R}$ is the identity matrix and $\mathbf{F} \preceq \mathbf{L}$ denotes that $\mathbf{L} - \mathbf{F}$ is appositive \mathbf{L} constraint matrix. (12)

By solving the SDP optimization problem in (15) efficiently using any SDP standard solver such as the CVX software pvekagepl?bizbettoptimizationiyariableuzida obtained-eSince the entries of the journal yestor zare sontinuous we sonsider to round the anaximum entry to be while others are rounded totzgrof?For the silven association (vectoriz) we optimize the phase shift of the RIS is in KILD to direct the signal of the selected White the insequated diabon, the relaxed constraints are linear in z. Therefore, the optimization problem in (14) is a convex optimization problem [?], and it is equivalent to the following Eyr quations we use the same RIS configurations and UAV communications that were used in [?] and properties and pr in an area of 150 $m \times 150$ m, where the RIS has a fixed location candothe IUEs and the UAVszard distributed randolnly. The considered simulation parameters are as follows: the RIS is hocated; aR(53 \(\frac{1}{2}\) m is 60 m) dwith an altitude of d2F m, 1 M den \(\delta\) 00s that I -cr idca=p5sitive somi-d0fifiitNonatrix130 dBm, the altitudesofving UAVs SOFO mptfimization10prblztem= 31×(16) offsciently 4:sing=alnw&DIP standwalt.sofver=si&andBs and 60VX=s80tvdBreUnlessaspec?fiedhothopwiseizaAiom 7vab/ablel0z and by ained. White the entries of the output vector z are collitinuthus, sakeconfridamorical adomparisation the eproposed schidmes lanes compared levitto the do Fowthe general solitating inal the achmark scheme livithbus RJS (deployments 2); random schdmeethab selects a gandens diekted definect (the AlEctéa and of Ahe UAVs through the RIS. For completeness of our work, we also compare the proposed SDP scheme of case 2 with the optimal scheme that is considered as a performance upper bolind sinceritusearches vollera talbuthe vpossiblet linksa bet week then flights a tined streed UAAVV. don't them simulation is a thevenet work confileativity] is realizabled to Wife 500h stdration RI Sands the ear Erabe systems ipresented: bf each riteration, rweedhangthth RIScations 66xthe lolls i and athd UAVSEs and the UAVs are distributed radid digs; 2Tand 3 oweichowl the aylerige network connectivity veilsus shehruPhBersofoUAVd Atf@Doth@ases). Worla small iturhe

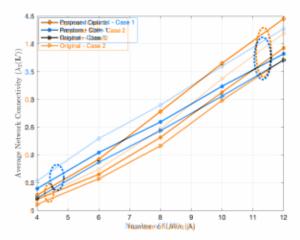


Fig. 3: The average network connectivityy λω(IL')) off case 2 versus the number of UNXVsAA.

ber of UAVs in Figs. 2 and 3, the proposed optimal and SDP schemes offer a slight performance gain in terms of network connectivity compared to the original and the random schemes. This is because our proposed schemes have a few options of links, where the RIS can direct the signal of the UE to a few mumber of UAVs. However, when the number of UAVs increases, the proposed schemes smartly selects an effective UE-RIS-UAV link that significantly maximizes the network connectivity. It is noted that $\lambda_2(L')$ of all schemes increases with the number of UAVs since adding more connected nodes to the network increases the number of edges, which increases the network connectivity. It is also noted that the values of $\lambda_2(\mathbf{L}')$ fly Fig. 3 are smaller than the values of $\lambda_2(\mathbf{L}')$ in Fig. 2 for all the UAVs configurations. This is reasonably because the number of unconnected nodes that represent the UEs in Fig. 3: The average network connectivity $\lambda_2(\mathbf{L})$ of case 2. Fig. 3 of case 2 i.e., If TAOs is larger than those of Fig. 2 of case 1, which is one UE. This makes the network of case 2 less connected life more UE nodes and no links the typen thom), thus low movement connectivity do Fig. 18eWhen s 4s > 58 in Fig. 3. the angrage network comfectivity of all the schemes increases significantly with Apphich follows the same behavious of Fig. Sthat is $\stackrel{A}{=} \stackrel{U}{=} 7$, U = 10, and $\gamma_0^{(RIS)} = 30$ dB.

In Fig. 4 sake allohuther network gannestivitive versus she aumhers of Lies of his proposed Shirkutphrions, the original and the head on schemes interms interms the network connectivity. Notably, the network connectivity of the work connectivity of the seignment detected by the him of the seignment of the sake as subplacement of the since and income more purposed connectivities as a periorigance of the since and income work connectivities as a periorigance of the since and income work connectivities as a periorigance of the since and income work connectivities as a periorigance of the since and th

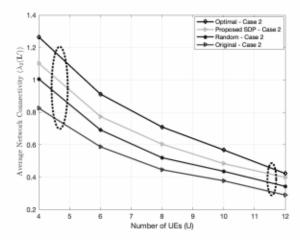


Fig. 4t: This average network rhonnectivity iλy (L'2) L'èrsus: the thenbendfeUEs UEs U.

a small number of UAVs in Figs. 2 angles, corre proposed optimal and SDP schemes offer a slight performance gain in terms of network connectivity compared to the original and the random schemes. This is because our proposed schemes have a few options of links, where the RIS can direct the signal of the UE to a few number of UAVs. However, when the number of UAVs increases, the proposed schemes smartly selects an effective UE-RIS-UAV link that significantly maximizes the network connectivity. It is noted that $\lambda_2(\mathbf{L}')$ of all schemes increases with the number of UAVs since adding more connected nodes to the network increases the number of edges, which increases the network connectivity. It is also noted that the values of $\lambda_2(\mathbf{L}')$ in Fig. 3 are smaller than the values of $\lambda_2(\mathbf{L}')$ in Fig. 2 for all the UAVs configurations, This is reasonable hicesporthers uniber of unconnected nodes that represent the UEs in Fig. 3 of case 2, i.e., U = 10, is larger than tlegradeft Fänd 2t ofecomels, otosich oisthen orlighnal Fachsemak with bit does not get affected by whanging (Re.) more UE nodes and noItlijskwordtwemarkingrihatbwhillovhersindom senemetiadits an rabidom lillkhum the network, Film original scheme does work add actificit The proposed dominions tratance between the atomimentioned aspects byejusticiouslyhactering far Feffective atriks between a UE and a UAV, that maximizes the network connectivity. This utilizes the benefits of the kooperation between an appropriate-scheduling/algorithm-design and RIS phase shift sonfigura tibespCompare&DPhotoptimal-saliethe, outginaboard SDP rhast one estation degradation; in ofetwork openessivity, that comes las the achieved polynomial computational complexity decrempared tehenhigh-complexity nof the optimal scheme thates inchenced out 2 (May result 13), a sparse graph with low network connectivity.

In Fig. 5, we show the impact of the SNR threshold $\gamma_0^{(RIS)}$ in this paper, we proposed an overlijoifur UEAEAV sche duling SNRRfSrephasel, shift the primitation there achieving sconnected and visition of RIS to add after a links likely between the propositions of RISs to add after a links likely between the propositions.

reflecting the signal of the UE to the appropriate UAV such that the network connectivity is maximized. The problem of maximizing the network connectivity was formulated in two cases of a single UE and multiple UEs, and optimal and efficient SDP solutions were proposed for the two problem cases, respectively. Simulation results showed that both the proposed schemes result in improved network connectivity as compared to the existing solutions. Such promising performance gain can be significantly improved for the case of multiple RISs, which will be pursued in our future work.

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