Enabling Interstellar Communication: RIS-Satellite-assisted Hybrid Computation Offloading for 7G Wireless Communication

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Abstract

Deep space exploration is an intriguing yet challenging pursuit, captivating researchers, and space enthusiasts alike who seek to unravel the mysteries of the universe. Mars, our neighboring planet, has been a key focus for scientists, leading to multiple missions aimed at revealing its secrets. In this study, reconfigurable intelligence surface (RIS) is employed to facilitate the task offloading scheme implemented within the Gale Crater. The simulation shows that the impact of RIS-aided Task Offloading on the Martian surface can enhance energy efficiency (EE) and minimize delay for users.

I. Introduction

Deep space exploration is a captivating yet challenging endeavor for researchers and space enthusiasts. Mars, a focus of numerous missions, gained attention with the 2012 arrival of the Curiosity Rover [1]. However, the Gale Crater's unique location poses communication challenges, including constraints in computational power, real-time data relay, limited energy, and intermittent sunlight, making it challenging to power up the rover and transmit data effectively. In the challenging Gale Crater terrain on Mars, direct communication links may face disruptions. Reconfigurable Intelligent Surface (RIS)-enabled wireless communication [2] is proposed as a potential solution. Emerging in sixth generation (6G) networks, RIS technology is cost-effective and energy efficient. It uses intelligent surfaces to reflect and redirect signals, aiming to overcome communication challenges in environments like the Gale Crater.

RIS, known for its signal reflection and redirection, is often combined with techniques like Task Offloading [3]. Task Offloading delegates intensive tasks to cloud servers or edge devices, reducing user energy consumption. Recent advancements include moving user tasks from Earth to Low Earth Orbit (LEO) satellites [4], suggesting improvements in extraterrestrial communication. In this study, reconfigurable intelligence surface (RIS) is employed to facilitate the task offloading scheme implemented within the Gale Crater. This involves offloading the tasks from the rover to either a low-orbit satellite or the Mars Habitat.

II. Proposed System and Problem Formulation

This study assumes in the gale crater followed shadowed rician fading, where the channel is composed of line of sight (LoS), non-LoS (nLoS) power ratio, and shadowed parameter, written as:

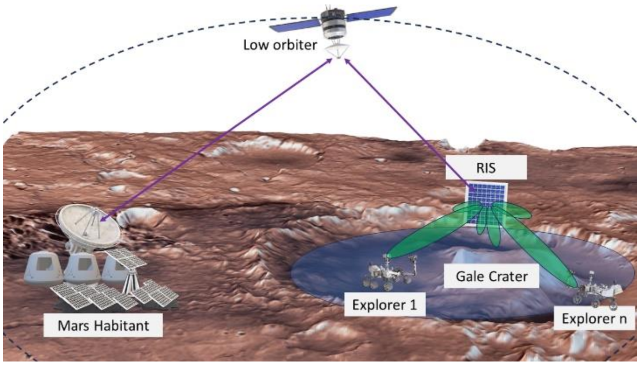

Fig.1. Proposed RIS assisted low orbiter hybrid task offloading.

$$p_A(a) = \frac{a}{b_0}\exp\left(\frac{-a^2}{2b_0}\right), \quad a \geq 0 \tag{1}$$

and

$$p_Z(z) = \frac{2m^m}{\Gamma(m)\Omega^m} z^{2m-1} \exp\left(\frac{-mz^2}{\Omega}\right), \quad z \geq 0 \tag{2}$$

With the aid of RIS, the channel gain uplink from users to RIS then to low orbiter is expressed as follows:

$$g_{\kappa,\varkappa} = \|\tilde{\boldsymbol{g}}_k^{\mathrm{H}} \boldsymbol{P}_k \Theta \tilde{\boldsymbol{h}}\|^2 \tag{3}$$

Finally, based on given channel gain, the uplink rates from user to satellite is written as follows:

$$R_{\kappa,\varkappa} = B\log_2\left(1 + \frac{g_{\kappa,\varkappa} p_\kappa}{\sum_{j \in \kappa \setminus \{\kappa\}} g_{j,\varkappa} p_j + \sigma^2}\right), \tag{4}$$

The energy consumption for local computation is denoted by:

$$E_{\kappa}^{L} = \varepsilon_{eff}\left(f_{\kappa}^{L}\right)^{2} X_{\kappa} \quad \forall \kappa \tag{5}$$

where X_k denotes a required computation, f_k is the computation CPU/cycles of the user.

This study proposed an energy minimization of users to optimally adjust the offloading decision while satisfying a limited communication time and computational capability. The problem formulated to minimize the total energy computation is written as follows:

$$\begin{aligned}
&\min_{\mathbf{W}_{\kappa},\mathbf{Q}_{\kappa}} \sum_{\kappa-1}^{\mathcal{I}} \sum_{\varkappa-1}^{\mathcal{M}} \left(1 - W_{\kappa,\varkappa} - Q_{\kappa,\varkappa}\right) E_{\kappa}^{L} + W_{\kappa,\varkappa} E_{\kappa,\varkappa}^{S} + Q_{\kappa,\varkappa} E_{\kappa,\varkappa}^{C} \\
&\text{s.t.} C1 : \sum_{\kappa \in \mathcal{I}} W_{\kappa,\varkappa} X_{\kappa} \leq Z_{\varkappa}, \quad \varkappa \in \mathcal{M} \\
&C2 : \sum_{v \in \mathcal{M}} \left(W_{\kappa,\varkappa} + Q_{\kappa,\varkappa}\right) \leq 1, \quad \kappa \in \mathcal{I} \\
&C3 : W_{\kappa,\varkappa} T_{\kappa,\varkappa}^{S} - Q_{\kappa,\varkappa} T_{\kappa,\varkappa}^{C} \leq T_{\varkappa} \quad \forall \kappa, \varkappa \\
&C4 : W_{\kappa,\varkappa}, Q_{\kappa,\varkappa} \in \{0, 1\} \quad \forall \kappa, \varkappa
\end{aligned} \tag{6}$$

C1 guarantees that every task that is offloaded to the satellite will not exceed satellite's computational capability. C2 guarantees that every user can only have one decision value, either uploading to satellite or cloud. C3 force every task offloading decision have to be lower than time coverage of satellite. C4 represents every task decision as 0 or 1, 1 means offload, while 0 means local computing.

$$\begin{aligned}
\min_{\hat{W}_{\kappa,i}^{\varkappa}, \hat{Q}_{\kappa,i}^{\varkappa}} \; & y_{\varkappa}(\boldsymbol{\lambda}) + \frac{\rho}{2} \sum_{\substack{i \in \mathcal{M} \\ \kappa \in \mathcal{I}}} \left\| \hat{W}_{\kappa,i}^{\varkappa} - W_{\kappa,i}^{(t)} + u_{\kappa,i}^{\varkappa(t)} \right\| \\
& + \frac{\rho}{2} \sum_{\substack{i \in \mathcal{M} \\ \kappa \in \mathcal{I}}} \left\| \hat{Q}_{\kappa,i}^{\varkappa} - Q_{\kappa,i}^{(t)} + v_{\kappa,i}^{\varkappa(t)} \right\|^{2} \\
\text{s.t.} \boldsymbol{\lambda} \in \phi_{\varkappa},
\end{aligned} \tag{7}$$

where p is the positive integer for penalty function and u,v is the slack variable based on augmented lagrange multiplier method. It can be seen that the problem now is quadratic with convex constraints. Therefore, it can be solved by utilizing interior dual point algorithm or CVX tools to obtained decision.

III. Result

Based on the proposed algorithm, it can be seen that the delta is reducing. It depicts for each iteration it is decreasing, then it is approaching a line and it can not reduce anymore. Hence, it is proven that the proposed alternating method is effective for low number of iterations.

IV. Conclusion

The proposed solution is the potential candidate for future generation communication where it can aid deep space exploration. Based on the proposed algorithm, it can reduce energy consumption better than with random decision. For the future direction, an extensive simulation needs to be done to prove that the proposed algorithm is suitable for Mars exploration.

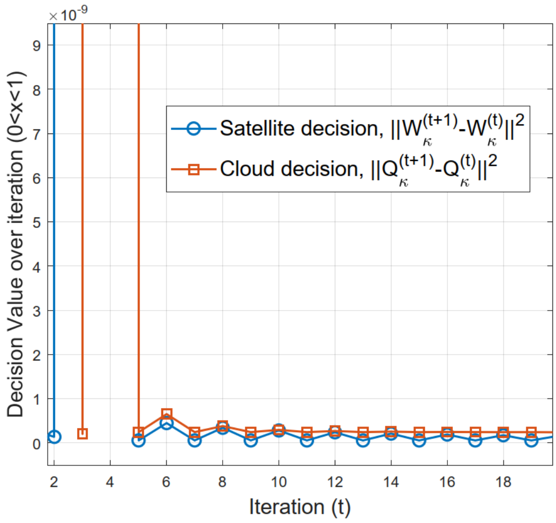

Fig.2. The result of proposed minimization algorithm.

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