Computer Communication Laboratory

Research Seminar

Resource Allocation for Optical IRS-Assisted Multi-UAVs Networks

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Outline of Presentation

I. Research Background

- The FSO-based HAP networks
- The optical IRS

II. System Description, Problem Statement and Goal

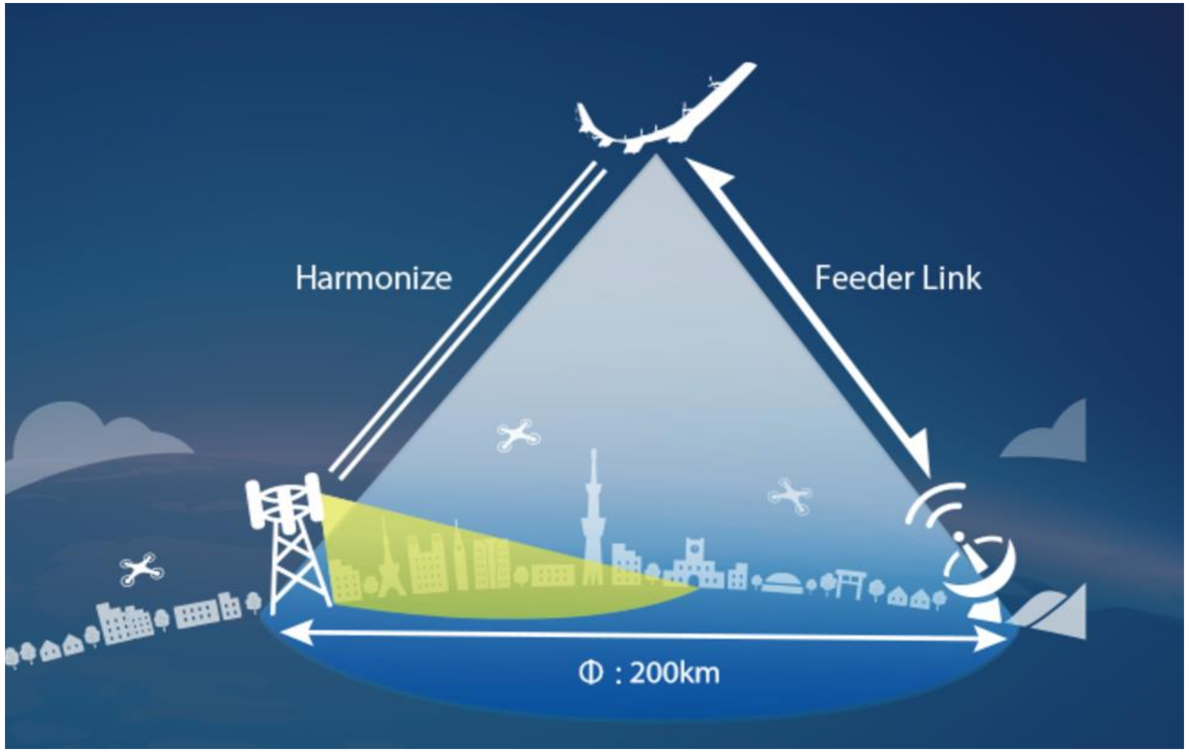
III. Proposed Resource Allocation

IV. Results

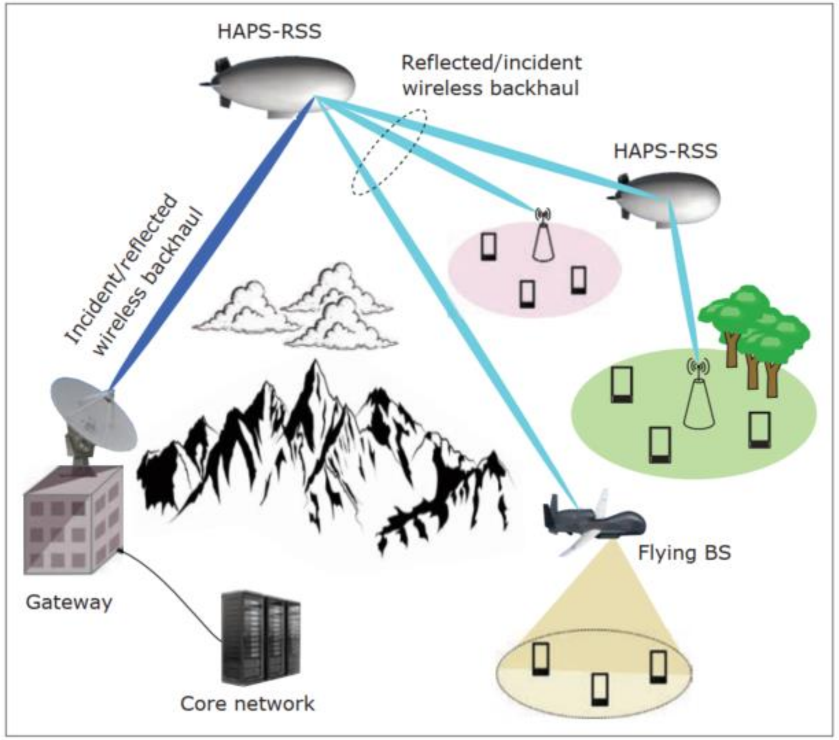
V. Conclusions and Future works

1. Research Background: the FSO-based HAP networks

In recent years, the success of various projects involving HAPs (e.g., SoftBank's Sunglider in Japan) has emerged potential of using HAP to provide internet from space.



Internet from space by **high altitude platform (HAP) by SoftBank [1]**

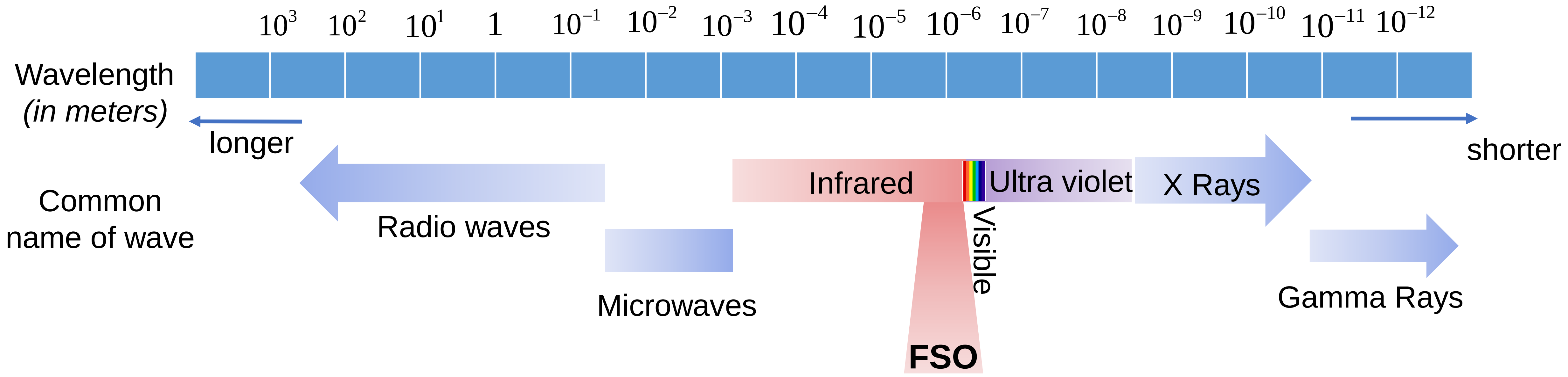


Backhauling support isolated users in remote rural areas using HAP

- Moreover, HAPs can serves ***as a relay node*** between core network other base stations to provide connectivity for end-users in rural/remote areas.

❖ Free Space Optical (FSO) communications

- Using near infrared frequency bands *(200-400 THz)* to transmit data.
- High-speed connection (Gbps and even Tbps)
- Free-license bandwidth



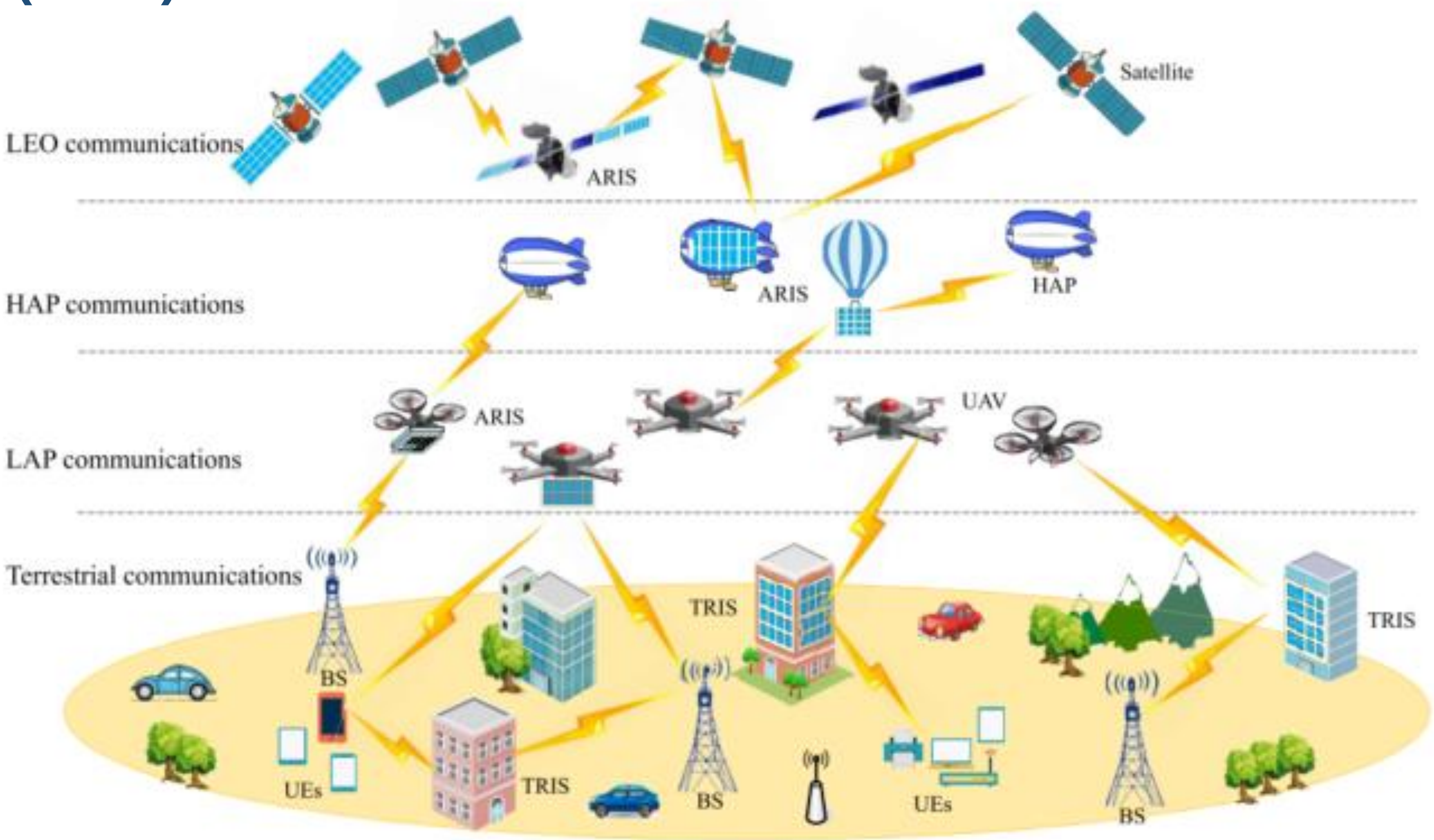
➡ **The FSO-based HAP system can provide *high data-rate and wide coverage.***

➡ However, using HAP as a relay can lead to *power consumption* and *hardware complexity*.

Recently, many studies have developed ***Intelligent reflecting surface (IRS)*** as *a green* and *alternative solution* of conventional relay networks.

❖ Optical Intelligent Reflecting Surface (OIRS):

- A surface ***reflect signal*** in a ***controlled way.***
- Comprises: an ***array of mirrors*** or ***metamaterial elements.***
- ***Nearly-passive:*** only low power is used.

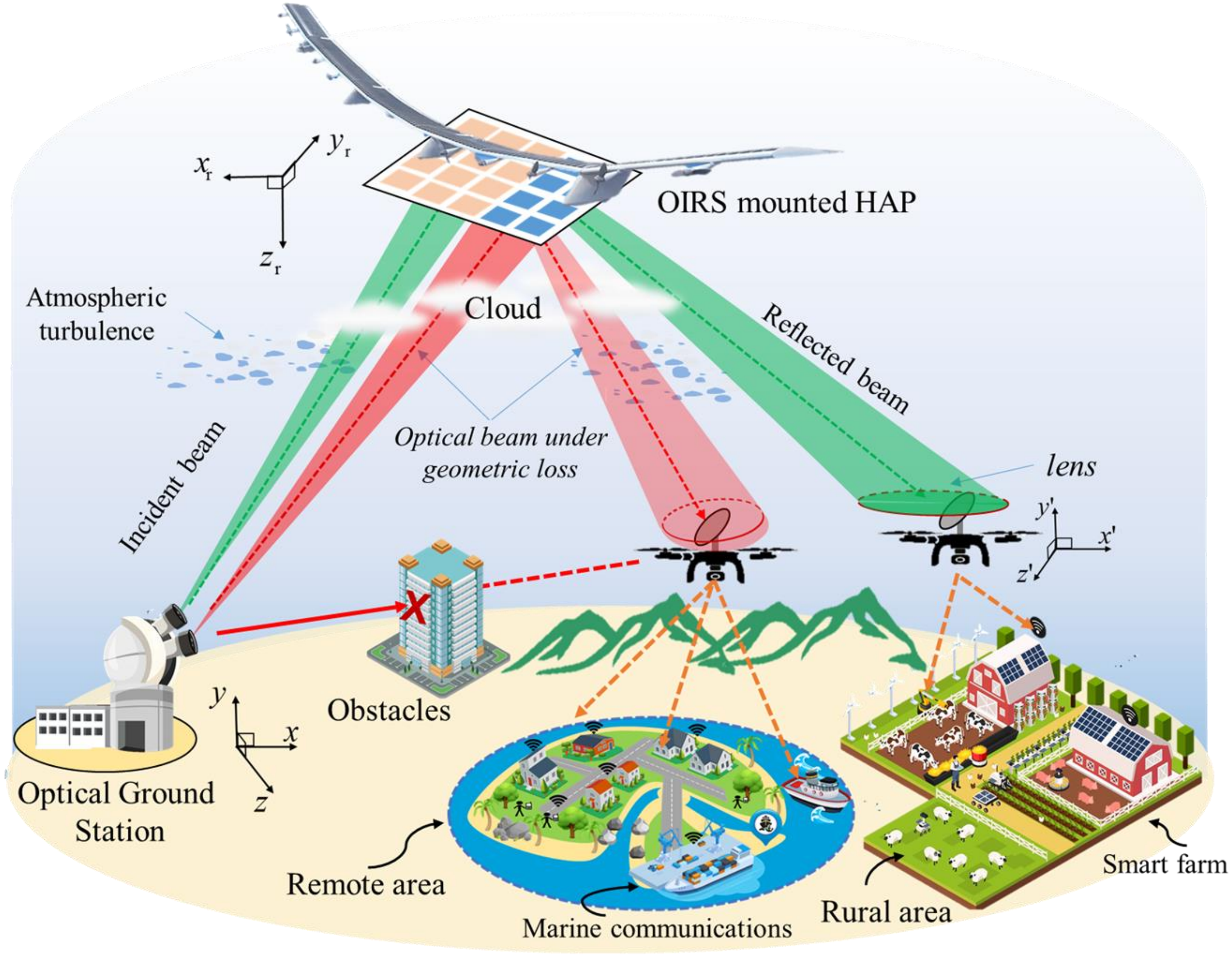


The operation concept of IRS [1]

❖ Advantages

- *Low energy consumption.*
- *Light payload, reduce hardware complexity compared to relay*
- *Extend coverage and avoid blockage.*

➡ ***OIRS can be equipped in HAP to reflect the FSO signal.***



FSO-based HAP-Assisted Multi-UAVs with IRS

❖ System description:

- **1. Source:** multiple laser sources in the optical ground station.
- **2.** One OIRS (an array of mirrors) mounted HAP.

$$\sum irs = L_x \times L_y$$

- Each mirror can rotate independently with angle θ to reflect the beam to expected users.
- **3. Destinations:** *N* UAVs mounted base stations in rural/remote areas.

❖ **Application:** provide the internet connection to rural/remote areas where ground stations are unavailable or assumed to be blockage connection.

- **Problem statement:** **The limited OIRS elements** mounted in HAP
  How to **sharing OIRS elements** to multiple UAVs ?

- **Goal:** Propose a **Resource Allocation Scheme** for OIRS to :
  (1) Maximize number of supported UAVs
  (2) Maximize the total achievable rate

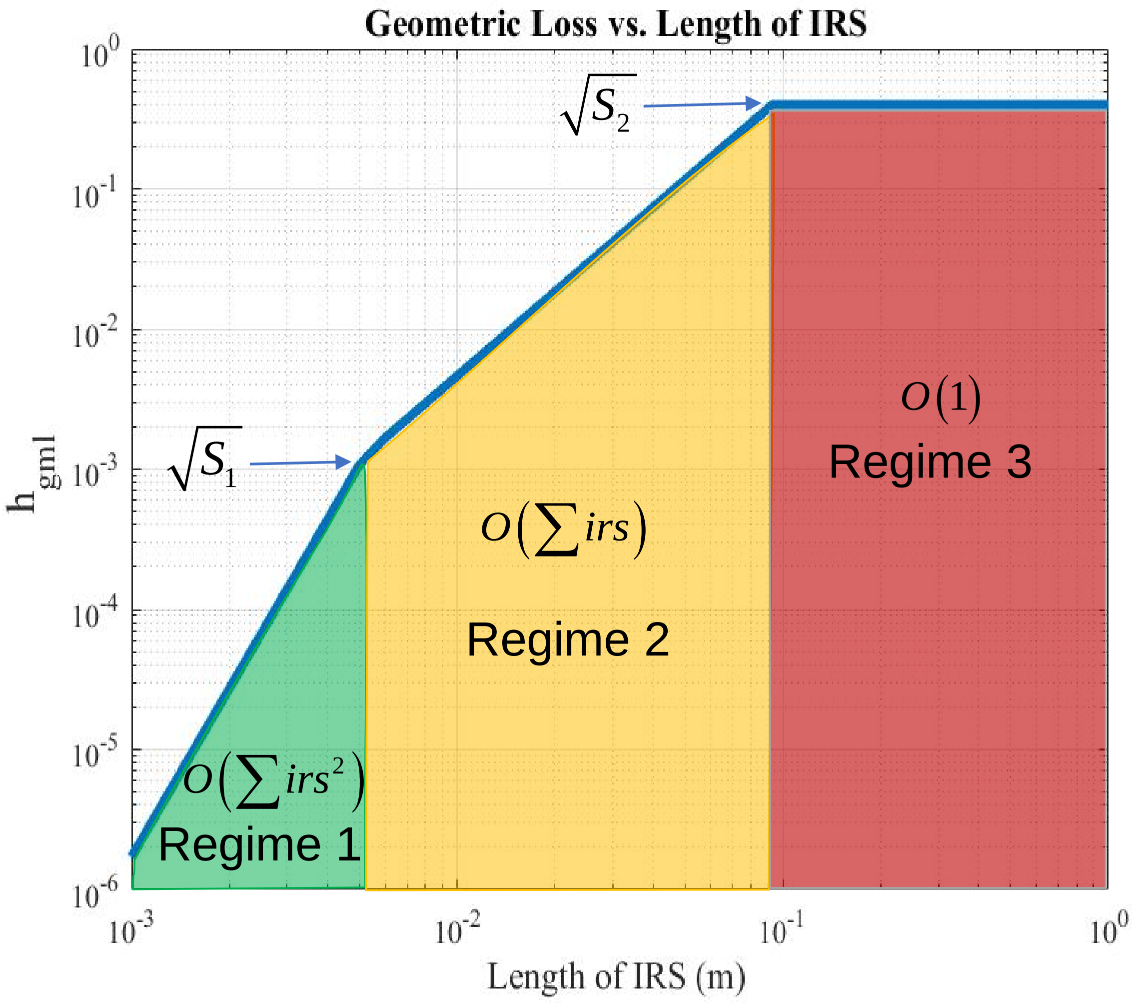
- **Steps:**
  - **Step 1:** Analyze ***the impact of IRS to channel condition.***

    How much the received power grows by increasing the number of IRS elements (mirrors)?

  - **Step 2:** Maximize number of supported UAV in set of *N UAVs. (Phase 1)*

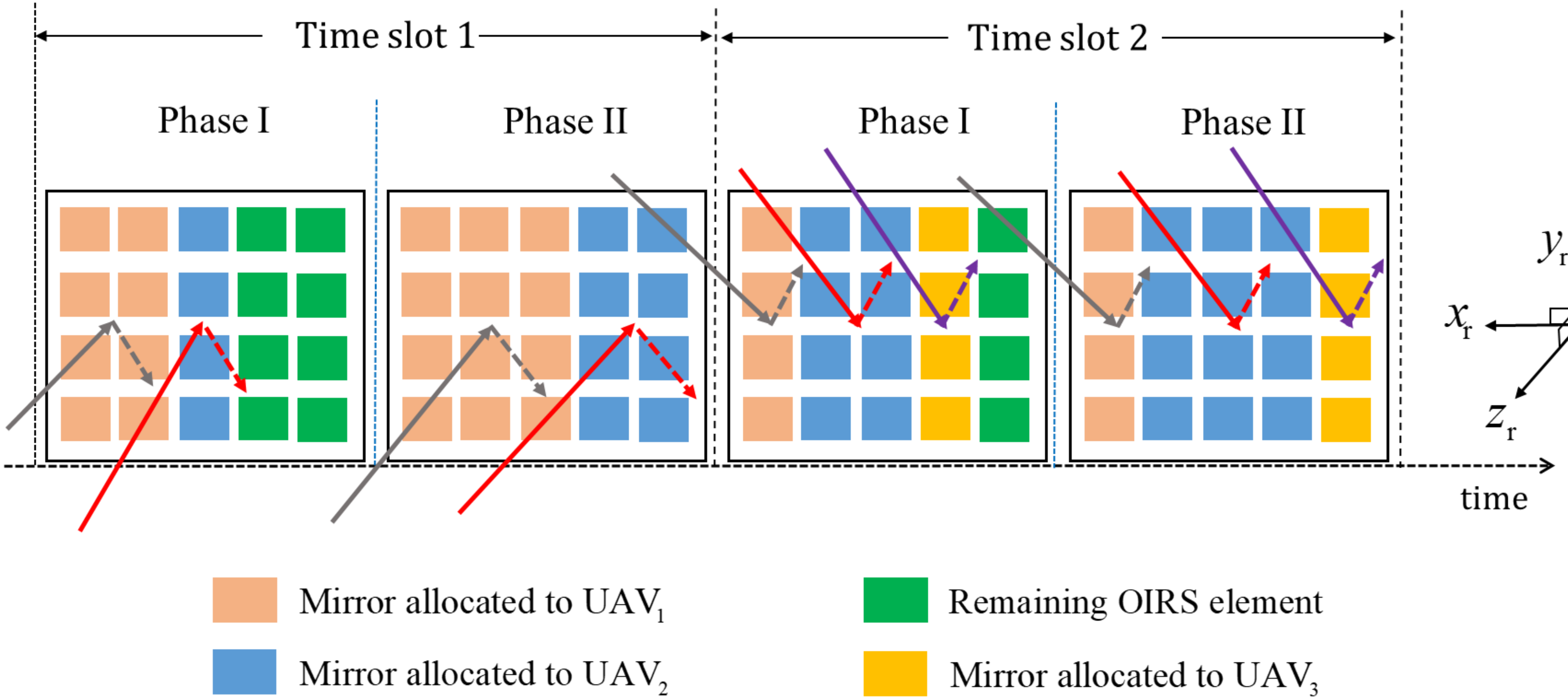
  - **Step 3:** Apply algorithm, i.e., exhausted search to ***allocate the remaining IRS elements*** to maximize the total achievable rate. *(Phase 2)*

- **IRS reflection coefficient:** imperfect reflection of IRS.
- **Cloud Attenuation:** laser beam energy loss due to absorption and scattering.
- **Atmospheric turbulence:** random variation of temperature and pressure of atmospheric cause the scintillation effect.
- **Geometric loss:** deterministic geometric loss due to the divergence of laser beam along the transmission path.



- The transmission process is divided into equal time slots, during which the OIRS is dynamically allocated to all supported UAVs using the proposed SRA scheme.

- SRA allocates each array of OIRS: fixed mirrors in y-axis, and allocate mirrors in x-axis



Algorithm 1 Resource Allocation to Operate UAVs

Input: N, P_t, $H_{U,i}$, $R_{\text{target},i}$, θ_i, θ_r, η, a, L_x, L_y
Initialize: Number of supported UAVs, $M \leftarrow 0$
for each UAV$_i$ **do**
    $\gamma_{\text{th},i} = 2^{\frac{R_{\text{target},i}}{B}} - 1$
    $h^*_{\text{gml},i} = \left(\frac{\gamma_{\text{th},i}\sigma_n^2}{e^{\sigma^2_{R,i}} \Re \eta P_t h_{c,i}} \right)^{1/2}$
    $G_3 = \left[\text{erf}\left(\sqrt{\frac{\pi}{2}} \frac{a}{\omega^{\text{mir}}_{rx,i}} \right) \right]^2$
    Calculate $S^*_{\text{irs},i}$ based on (12),(13)
    $L^*_{x,i} = \left\lceil \frac{S^*_{\text{irs},i}}{L_y} \right\rceil$
end for
$\mathbb{L} = \{ L^*_{x,i} \mid i = 1, 2, \ldots, N \}$
Sort $\mathbb{L}$ in descending order.
for each UAV$_i$ in the sorted list $\mathbb{L}$ **do**
    if $L_x - L^*_{x,i} \geq 0$ **then**
        Allocate $L^*_{x,i}$ to UAV$_i$.
        $M \leftarrow M + 1$
        $L_x \leftarrow L_x - L^*_{x,i}$
    else
        Do not support UAV$_i$.
    end if
end for
Output: Maximum number of operating UAVs, M
Required OIRS size for each UAV$_i$, $L^*_{x,i}$
Remaining OIRS resource, $L_{\text{rm}} = L_x$

Phase I: maximum number of supported UAVs

Input

Calculate required IRS for each UAV to achieve QoS, 1Gbps

Allocate IRS to UAV that requires the lowest IRS

Output

Algorithm 2 Maximize Total Achievable Data Rate

```
Input: M, L_rm, L*_{x,i}, h*_{gml,i}, B, P_t, η, h_{c,i}, σ_n.
for each UAV_i do
    γ_i = ( ℜ P_t η h_{c,i} h*_{gml,i} / σ_n )^2 E[h^2_{p,i}]
    R_i = B log_2(1 + γ_i)
end for
R_total = Σ_{i=1}^{M} R_i
while  L_rm > 0  do
    for each UAV i do
        L_{x,i} = L*_{x,i} + 1
        Calculate h*_{gml,i} based on (4), (6)
        γ_i = ( ℜ P_t η h_{c,i} h*_{gml,i} / σ_n )^2 E[h^2_{p,i}]
        R_{new,i} = B log_2(1 + γ_i)
        R_{total,i} = R_total − R_i + R_{new,i}
        Add R_{total,i} to ℝ
    end for
    Identify UAV*_i with R_{total,i} = max(ℝ)
    R_total ← max(ℝ)
    Allocate an OIRS element to UAV*_i
    L*_{x,i*} ← L*_{x,i*} + 1
    L_rm ← L_rm − 1
end while
Output: Maximum total achievable data rate of operating UAVs, R_total.
```

Phase II: maximum total achievable data rate

Input

Calculate total achievable rate when allocate one IRS array to each UAVs

Identify the UAV providing highest total achievable rate

Output

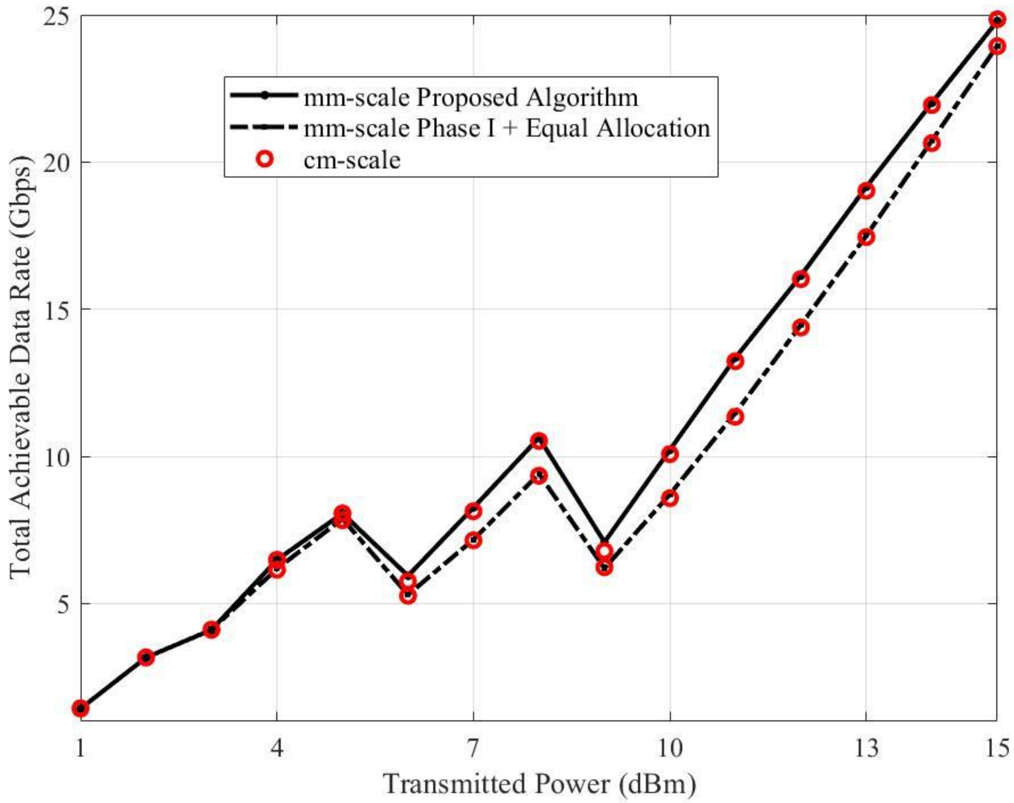
3. Proposed Spatial Resource Allocation (SRA)

- The SRA scheme calculates all the possible cases of allocating OIRS elements to maximize the total achievable data rate.

- How large the IRS element should be?

Cloud Type	Algorithm Running Time (s)		Total Achievable Data Rate (Gbps)	
	cm scale	mm scale*	cm scale	mm scale
Nimbostratus (N_c = 200 cm^{-3})	0.0532	0.3794	10.3146	10.2750
Cumulus (N_c = 250 cm^{-3})	0.0567	0.4267	9.8805	9.8012
Altrostratus (N_c = 400 cm^{-3})	0.0622	0.4651	3.6033	3.6033

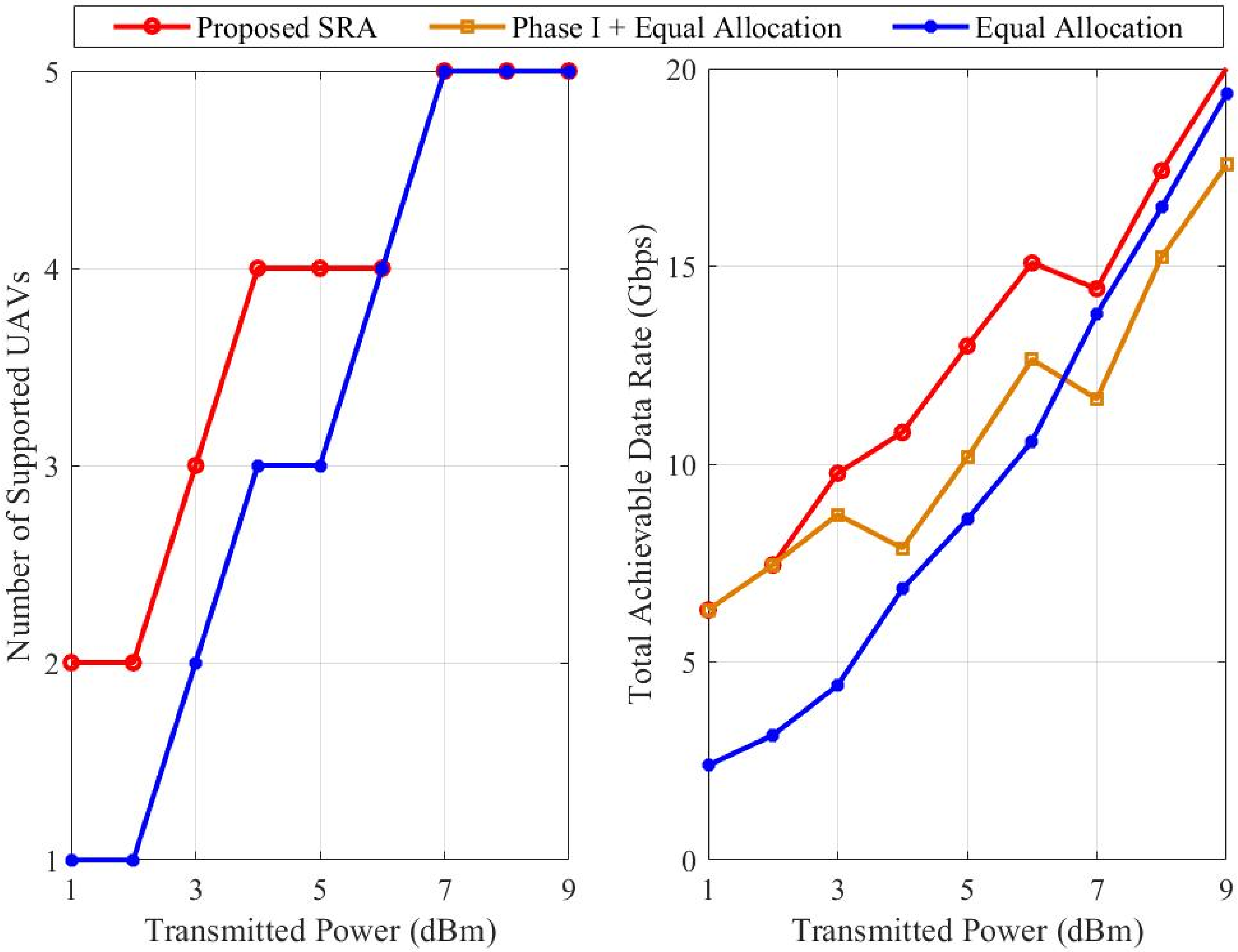
TABLE I: Algorithm running time and total achievable data rate for different cloud types with OIRS elements in cm and mm scales.



➡ Selecting an OIRS element size of 1 cm is preferable, as it ensures the proposed algorithm achieves feasible running times.

*Intel(R) Core (TM) i9-10900 CPU @ 2.8GHz, 2801 Mhz, 10 Core(s), 20 Logical Processor

- Benchmark
  - Proposed SRA
  - Phase I + Equal Allocation in Phase II
  - Equal Allocation
- The proposed SRA outperforms the others allocation.
- Given a transmitted power, SRA supports more UAVs and provides higher total achievable rate.
- SRA effectively allocate the IRS elements to UAVs.



5. Conclusion and Future Improvements

❖ **In this work, I proposed a spatial resource allocation for OIRS to support multiple UAVs.**

- The proposed scheme maximize the number of operating UAVs at first and maximize the total achievable data rate.

- The results demonstrates the effectiveness of proposed scheme.

❖ **Future work:**

- Channel: considering pointing error, derive the geometric loss under the impact of pointing error.

- Propose other optimization solution for SRA.

THANK YOU FOR LISTENING!