EPLA: Energy-balancing Packets Scheduling for Airborne Relaying Networks

Never Stand Still Engineering

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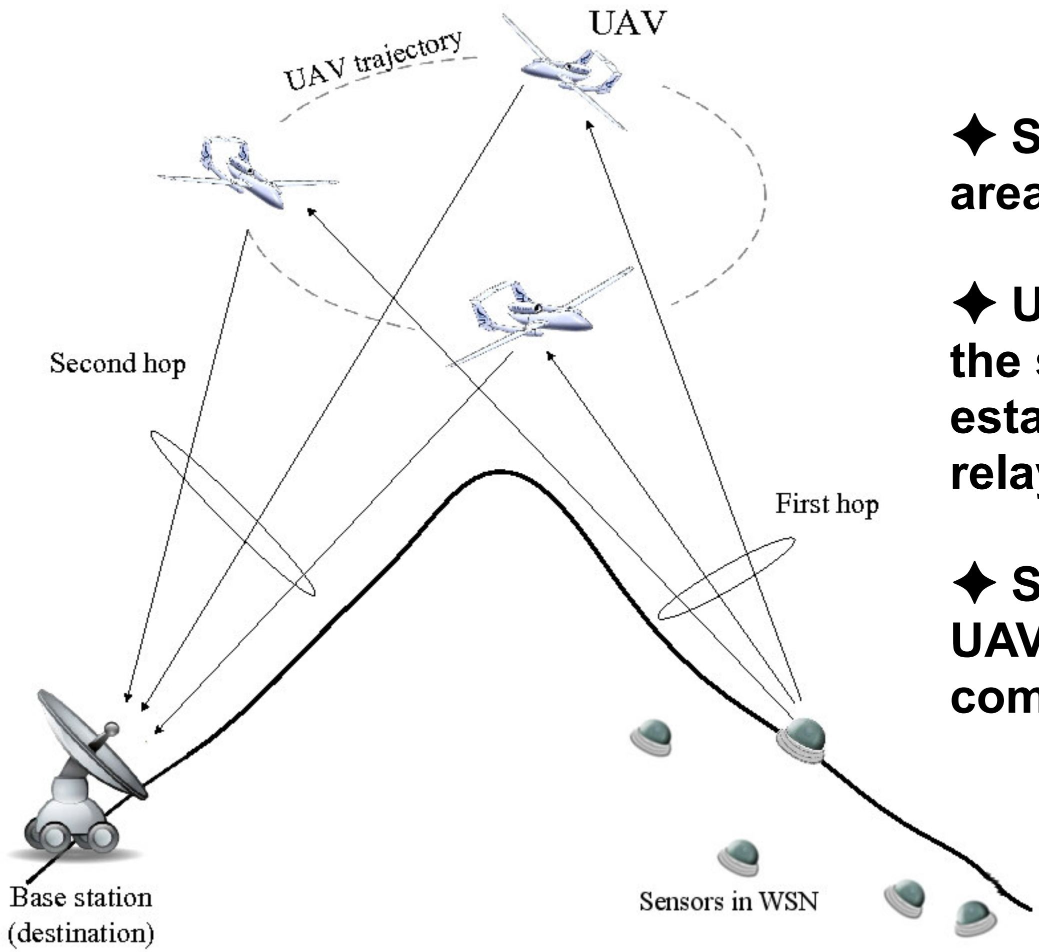
Outline

- ✦ Research Background
- ✦ Challenges
- ✦ System Model
- ✦ Packet Load Scheduling for UAVs
- ✦ Simulation Evaluation
- ✦ Conclusion and Future Work

Airborne Relaying Networks



✦ Sensors are deployed in remote areas.

✦ UAVs are deployed to fly over the source and the destination, establishing a multi-hop wireless relaying transmission link.

✦ Sensor nodes transmit data to UAVs once they fly in their communication range.

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Challenges

- ✦ **Variant link quality**

  ~ experiments in [1] and [2] characterised the link behaviour in airborne relaying networks.

  ~ the wireless channels between the ground nodes (i.e., sensors and BS) and the aerial relays are highly dynamic and prone to packet loss.

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✦ **Limited battery capacity of UAVs**

~ data collection would be frequently interrupted, because the UAV needs to be recharged.

~ round-robin relaying of multiple UAVs can relieve this problem to some extent.

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✦ Variant link quality

~ experiments in [1] and [2] characterised the link behaviour in airborne relaying networks.

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distributing the packet load while ensuring a balanced energy drain amongst the UAVs given the uncertain channel dynamics.

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System Model

Number of UAVs	N_R
Number of packets successfully received	S_i
Distance between the source node and UAV i at time t	$d_{src,i}(t)$
Total number of data packets	M_R
Antenna gains of the transmitter and receiver	G_{tx} G_{rx}
Transmit power of of the source node	P^{tx}_{src}

System Model

✦ **First hop: average SNR between the source node and UAV i at time t**

$$\overline{\gamma}'_i(t) = \frac{P^{tx}_{src}}{K_1 N_0 d^{K_2}_{src,i}(t)}.$$

K2 is path loss component
K1 ~ f(Gtx, Grx, wave length)

Power of AWGN

System Model

- ✦ **First hop: average SNR between the source node and UAV i at time t**

$$\overline{\gamma}'_i(t) = \frac{P_{src}^{tx}}{K_1 N_0 d_{src,i}^{K_2}(t)}.$$

- ✦ **At time t, the outage probability at UAV i**

the SNR threshold required for successful reception at the UAV

$$\Pr(\gamma'_i(t) < \gamma_0) = \int_0^{\gamma_0} p(\gamma'_i(t)) d(\gamma'_i(t)) = 1 - \exp(\frac{\gamma_0}{\overline{\gamma}'_i(t)}),$$

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- The packet error probability at UAV i

$$\Pr_{src,i}(t) = 1 - \exp(-K_{src} \cdot d_{src,i}^{K_2}(t)),$$

$$K_{src} = \frac{K_1 N_0 \gamma_0}{P_{src}^{tx}}.$$

System Model

✦ Similar to the first hop, we define the SNR of the second hop as $\gamma_i(t)$

$$\gamma_i(t) = H_i(t)\frac{\Gamma_i(t)}{N_0},$$

~ The $\Gamma_i(t)$ indicates minimum transmit power of UAV i at time t

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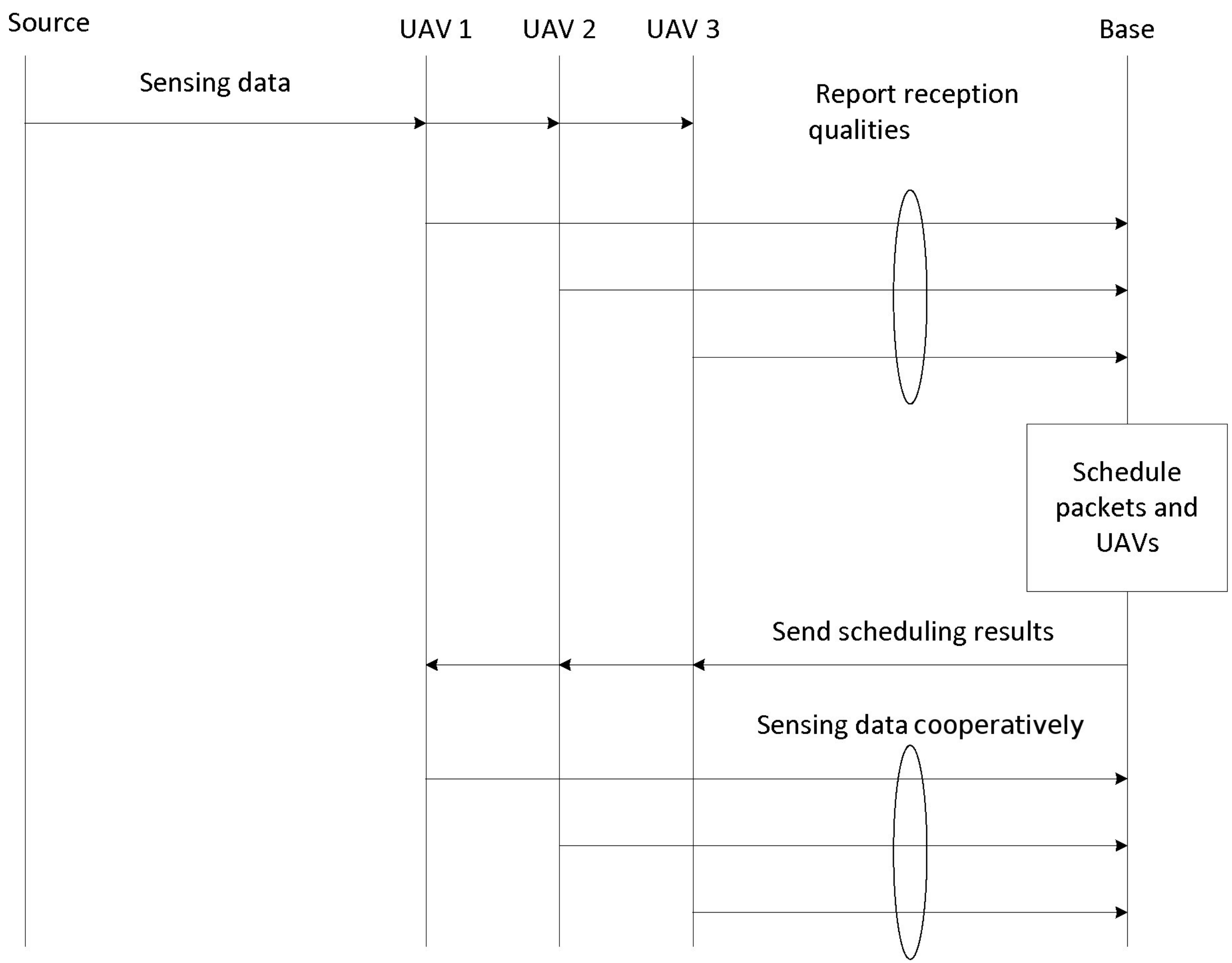
Relaying Protocol of Cooperative UAVs



Problem Formulation

- The instantaneous bit error rate (BER) ϵ_i for UAV i

$$\epsilon_i \approx \kappa_1 \exp\left[\frac{-\kappa_2 \gamma_i(t) \Gamma_i(t)}{2^{\rho_i} - \kappa_3}\right],$$

K1 and K2 are two constants relating to the channel

K3 is a real constant

ρi denotes a finite set of AMC modes for UAV i

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✦ ϵ_i **is limited by the system requirement ϵ, therefore, to fulfil the BER requirement, we have**

$$\Gamma_i(t) = \delta_i(t) \cdot (2^{\rho_i} - 1),$$

$$\delta_i(t) = \frac{\kappa_2^{-1} \ln(\frac{\kappa_1}{\epsilon})}{\gamma_i(t)}.$$

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✦ **Given the modulation level ρ_i and the packet size $\mathfrak{L}_p^{s_i}$**

$$\pi(s_i, \rho_i, t) = \mathfrak{L}_p^{s_i} \cdot \delta_i(t) \cdot \frac{(2^{\rho_i} - 1)}{\rho_i}.$$

Packets Scheduling Optimisation Problem

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$$\min_{x_{i,s,\rho_i}} \left\{ \max_{i\in[1,N_R]} \sum_{s\in\mathbb{S}_i} \sum_{\rho_i=1}^{\rho_M} x_{i,s,\rho_i} \cdot \delta_i(t) \cdot \frac{2^{\rho_i}-1}{\rho_i} \right\}$$

→ **Minimise the largest energy consumption of all the UAVs**

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$$subject\ to: \sum_{\rho_i=1}^{\rho_M} \left[x_{i,s,\rho_i} \Gamma_i(t) \right] \leq P_{max}, \ \forall s \in \mathbb{S}_i$$

$$\sum_{\rho_i=1}^{\rho_M} x_{i,s,\rho_i} \leq 1, \ \forall s \in \mathbb{S}_i$$

→ **Any data packet can only be forwarded by one AMC mode of a UAV**

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$$\sum_{i\in\{j:s\in\mathbb{S}_j\}} \sum_{\rho_i=1}^{\rho_M} x_{i,s,\rho_i} = 1,\ \forall s \in \bigcup_{i=1}^{N_R} \mathbb{S}_i$$

→ **The packets that have been correctly received by the UAVs is forwarded by one of the UAVs that have correctly received the packet**

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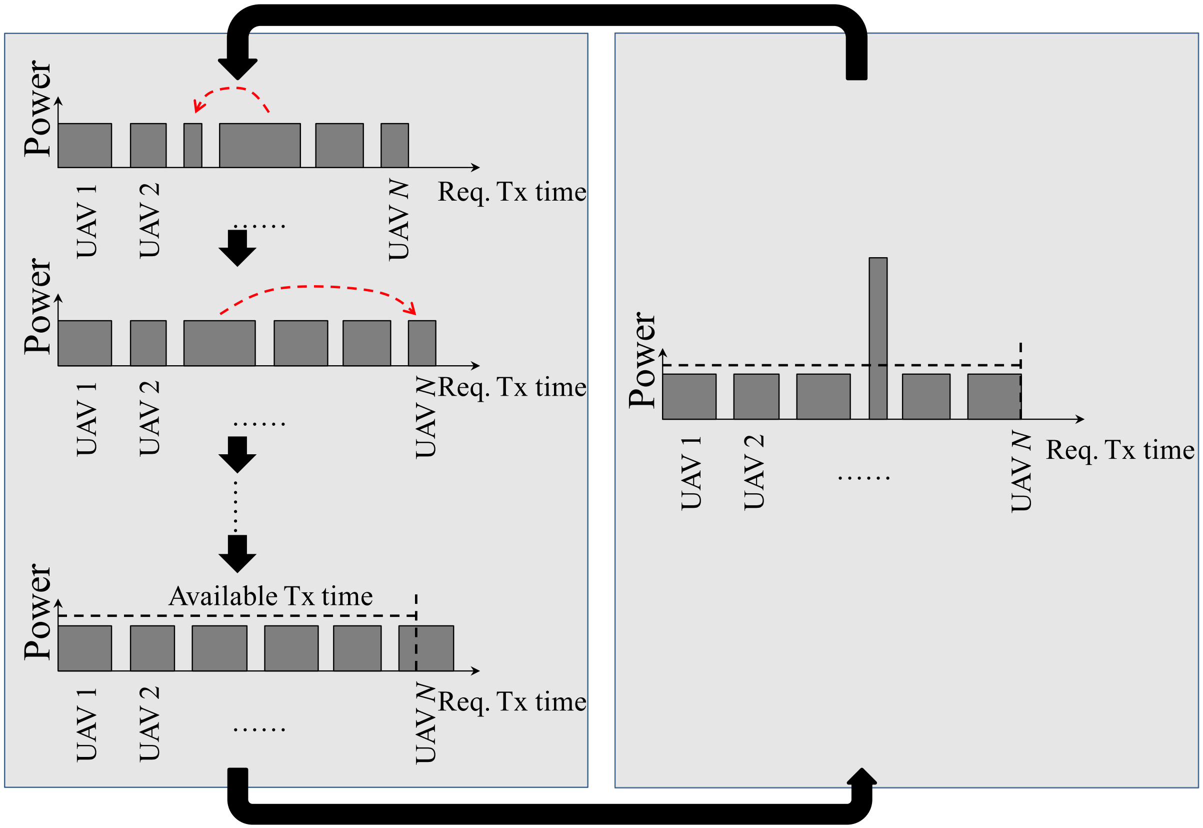
→ **The packets that have been correctly received by the UAVs is forwarded by one of the UAVs that have correctly received the packet**

$$\sum_{i \in \{j : s \in \mathbb{S}_j\}} \sum_{s \in \mathbb{S}_i} \sum_{\rho_i=1}^{\rho_M} \frac{x_{i,s,\rho_i}}{\rho_i} \leq \frac{T}{\mathfrak{L}_p}$$

↓ **All UAVs complete forwarding packets in the scheduled timeslot of T**

EPLA Heuristic

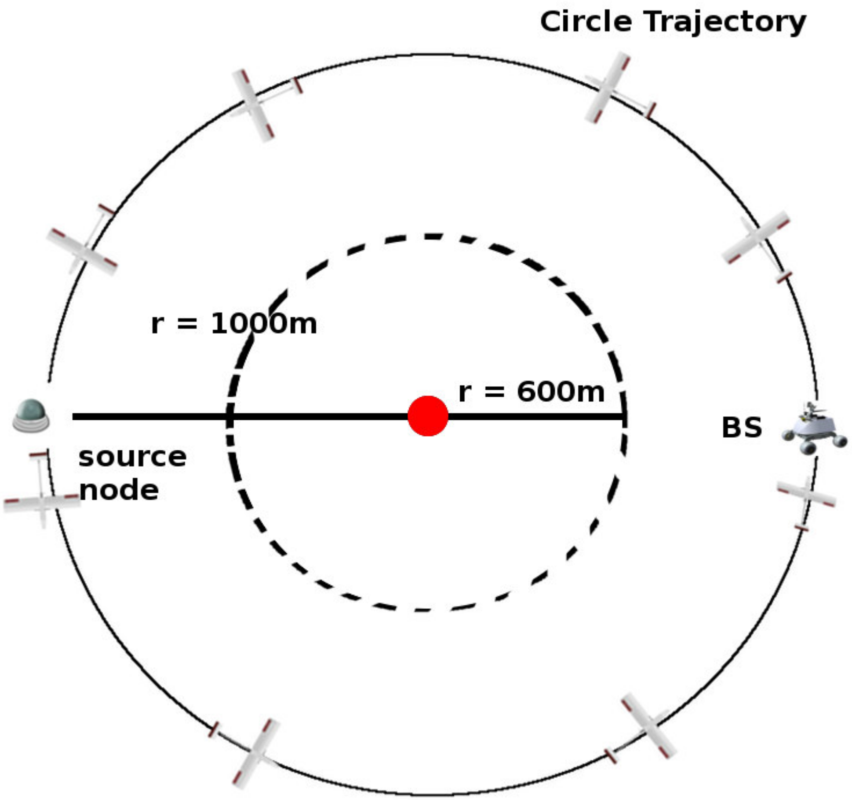


✦ **Energy balancing and modulation adjusting are decoupled and conducted in an iterative manner.**

✦ **The above steps are repeated until the difference of energy consumption stops decreasing**

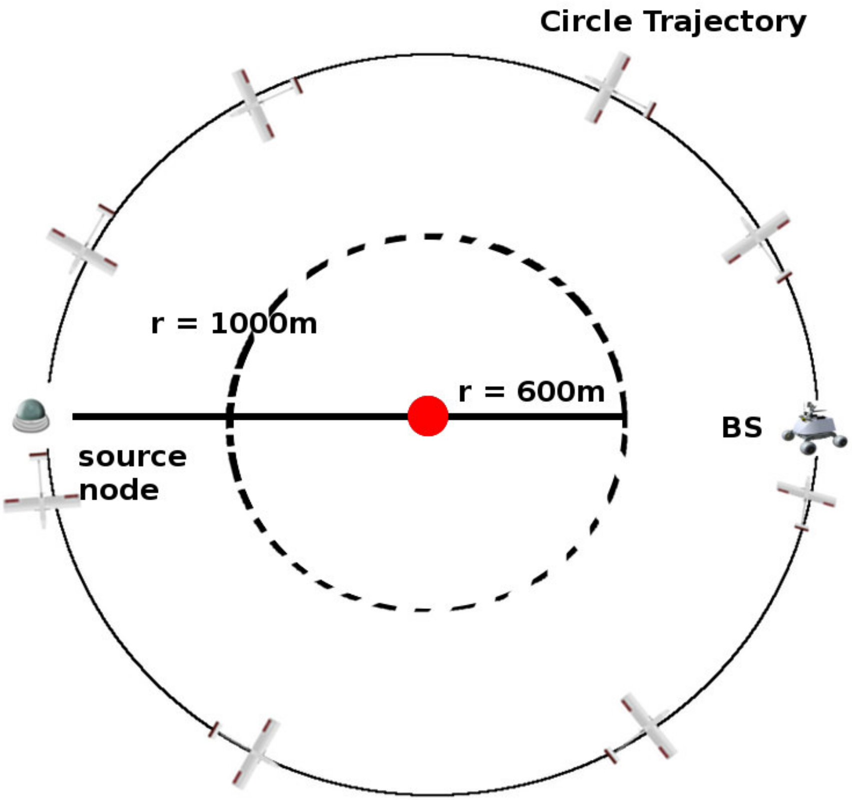
Outline

Simulation Model and Parameters



✦ **The UAVs are uniformly distributed on the circular trajectory between the source and BS.**

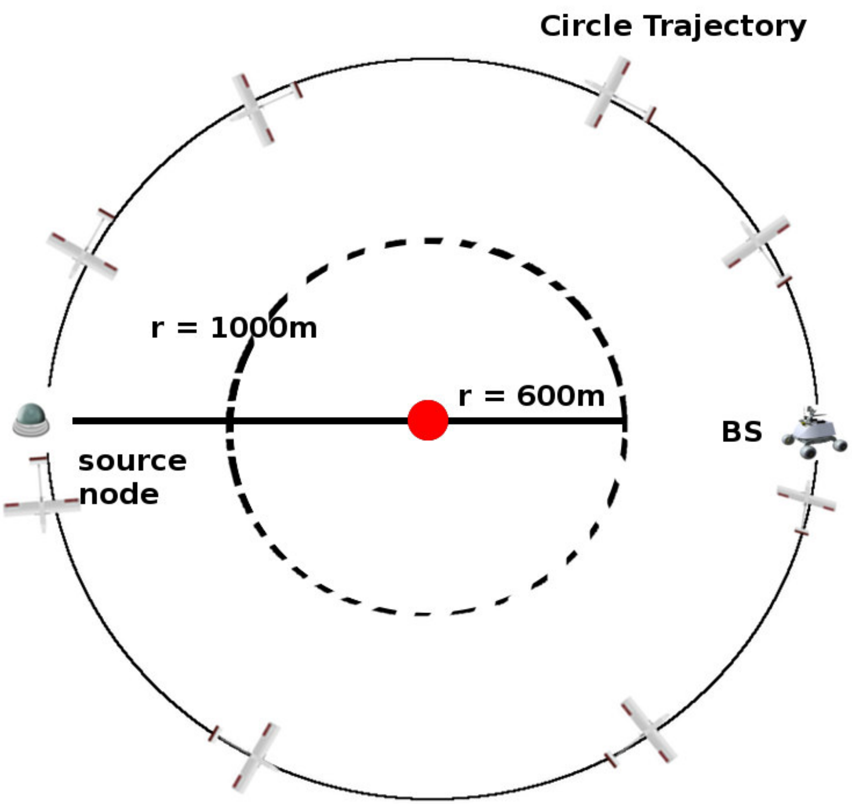
Simulation Model and Parameters



✦ **The UAVs are uniformly distributed on the circular trajectory between the source and BS.**

✦ **The radius of the circular trajectory r changes from 200m to 1000m.**

Simulation Model and Parameters



✦ The UAVs are uniformly distributed on the circular trajectory between the source and BS.

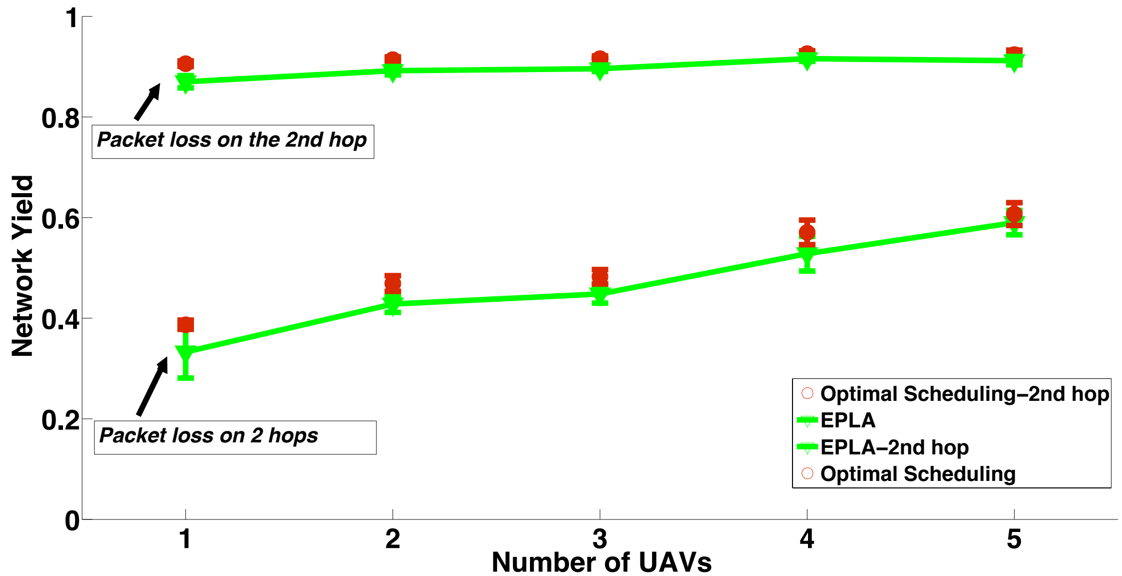
✦ The radius of the circular trajectory r changes from 200m to 1000m.

✦ The distance between the source node and BS is 2km and all the UAVs fly at the same speed which is 10m/s. The wireless links between the source node and UAVs, UAVs and the BS are modelled by block fading channels.

Performance Evaluation

✦ **Compared with the optimal strategy**

Network yield



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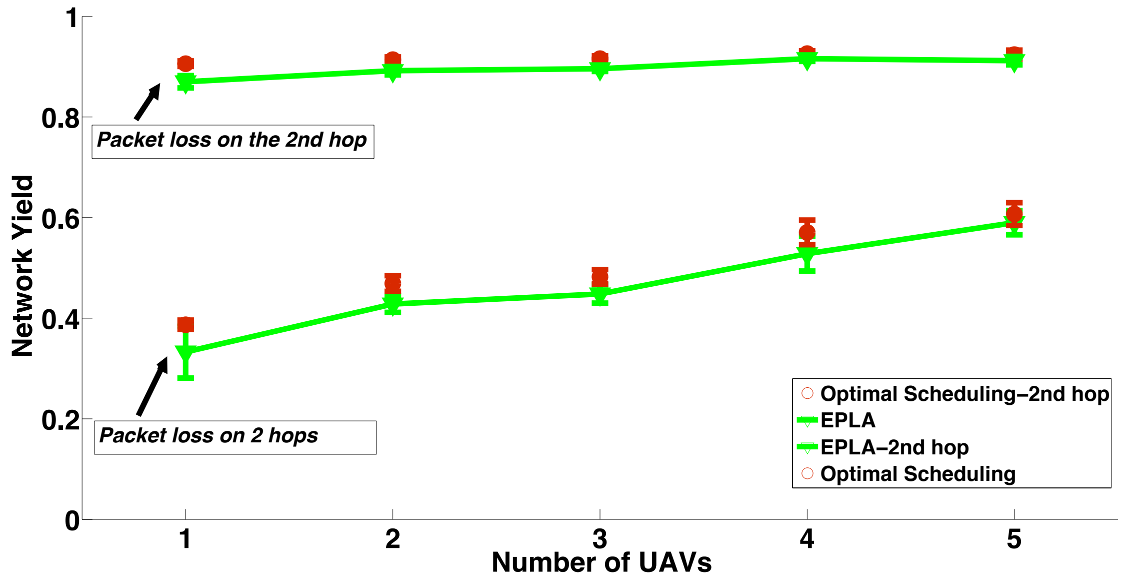
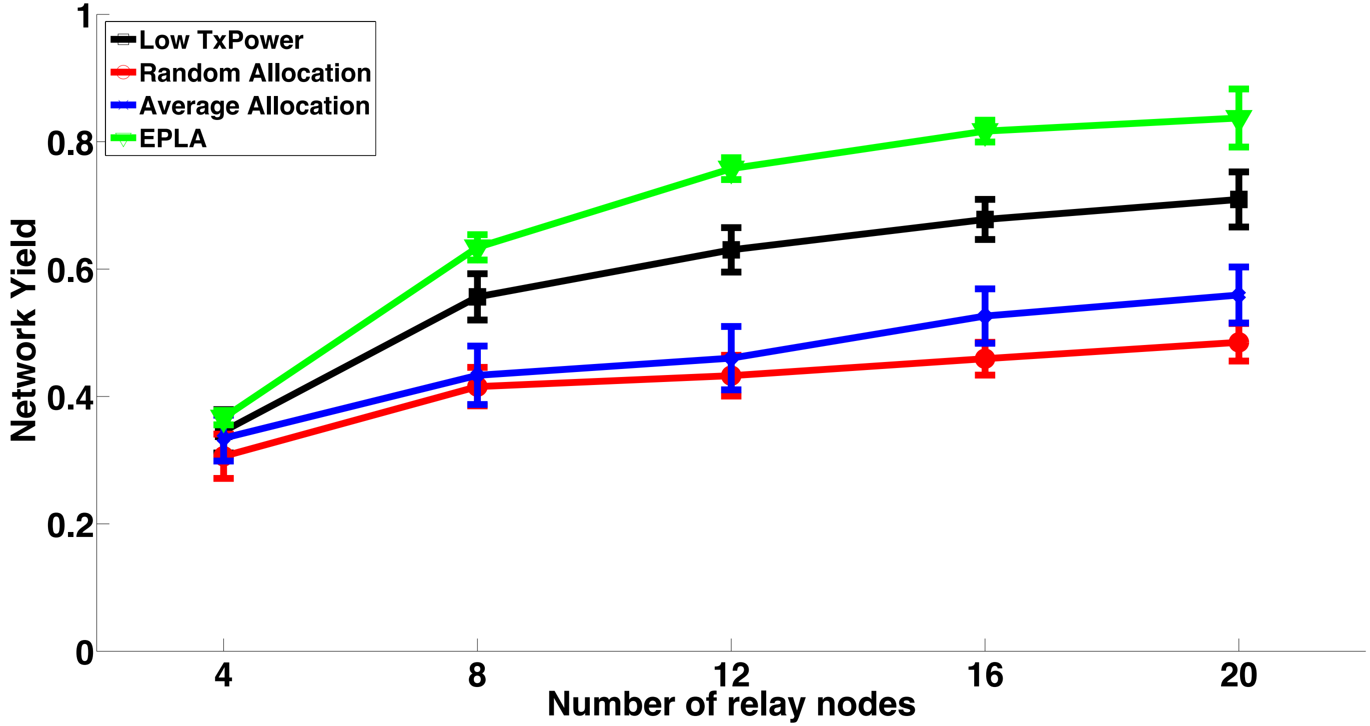


UAVs	Optimal Schedules		EPLA	
	mean	variance	mean	variance
1	0.56s	0.000022	0.039s	0.000015
2	19.06s	1.6291	0.0438s	0.000013
3	42.6540s	0.5993	0.0477s	0.000039
4	50.0191s	12.4113	0.0507s	0.000019
5	129.1360s	147.9916	0.0664s	0.00003

Runtime

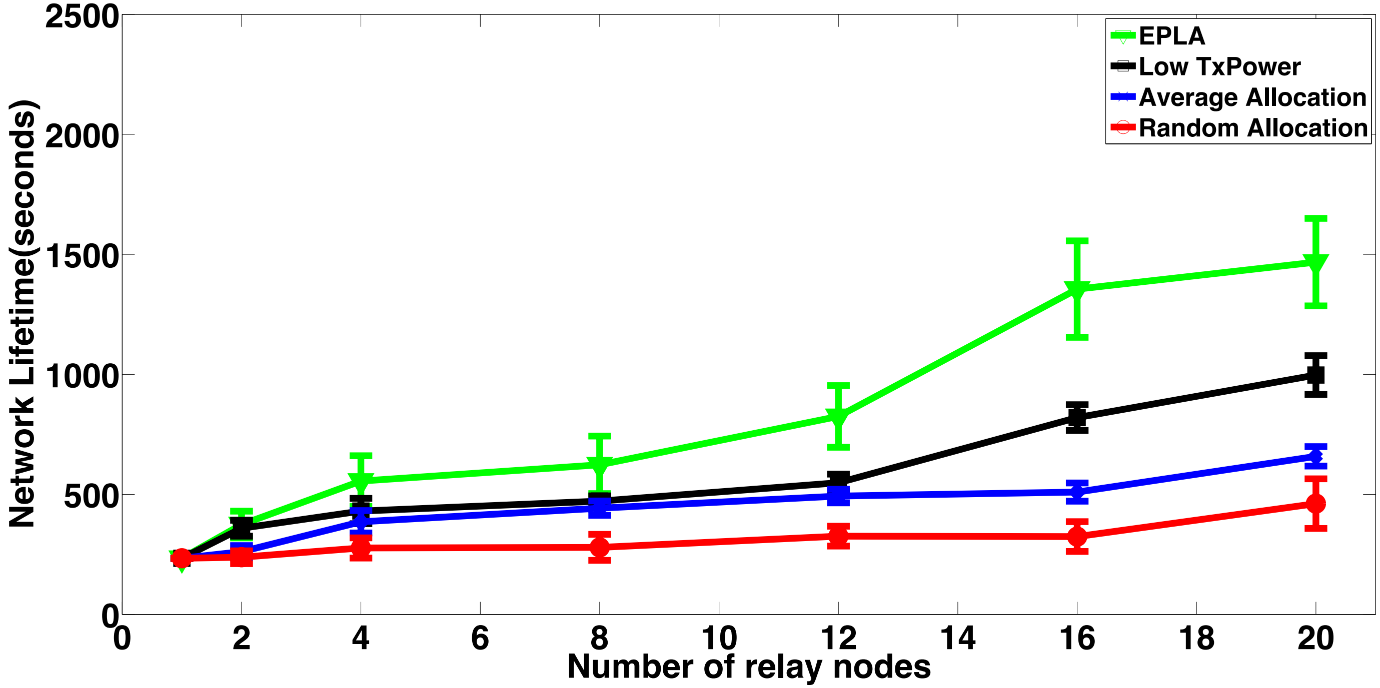
Performance Evaluation

✦ **Comparison of network yield with different packet scheduling algorithms. The error bar shows the standard deviation over 100 runs.**



Performance Evaluation

✦ The performance of network lifetime with different packet scheduling algorithms. The error bar shows the standard deviation over 100 runs.



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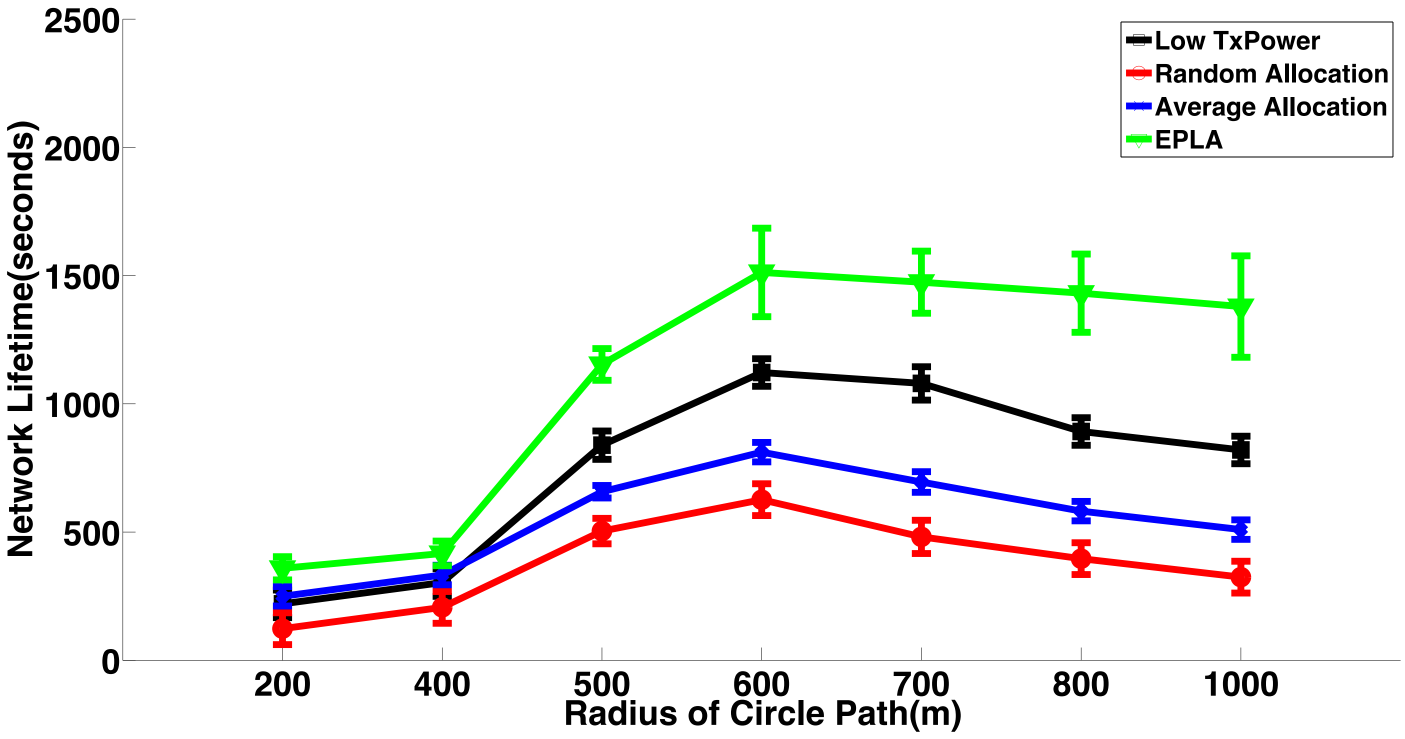

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Conclusion and Future Work

✦ We proposed an energy-efficient relaying scheme which can extend the lifetime of cooperative UAVs in human-unfriendly environments;

✦ An NP-hard optimisation problem was formulated to guarantee packet success rates and balance energy consumption;

✦ A practical suboptimal solution was developed by decoupling energy balancing and modulation selection;

✦ It is also revealed that our scheme can increase network yield by 15%, and extend network lifetime by 33%, compared to existing greedy algorithms;

✦ More UAV trajectories will be investigated in our experiment. To increase communication range of the UAV, a hybrid antenna for the UAV will be combined with EPLA algorithm.

Reference

✦[1] Bekmezci, O. K. Sahingoz, and S¸. Temel, “Flying ad-hoc networks (fanets): a survey,” Ad Hoc Networks, vol. 11, no. 3, pp. 1254–1270, 2013.

✦[2] N. Ahmed, S. S. Kanhere, and S. Jha, “Utilizing link characterization for improving the performance of aerial wireless sensor networks,” Journal on Selected Areas in Communications, vol. 31, no. 8, pp. 1639–1649, 2013.

Thank You!

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