UNPR: Uncovered Neighbor-aware Probabilistic Relay-Selection Method in Tactical FANETs

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Abstract—To increase the coverage probability while reducing unnecessary packet transmissions, realizing efficient and effective relay selection is important, we propose an Uncovered Neighbor-based Probabilistic Relay (UNPR) method that considers flying ad hoc network (FANET) topological dynamics. We devise a relay decision factor to identify relay UAV candidates, and the final probabilistic relay decision reduces coverage overlaps and minimizes redundant packet transmissions. Through extensive simulations, it has been validated that the proposed UNPR method surpasses the benchmark methods in terms of the total number of transmissions, coverage probability, and energy efficiency. This superiority is observed across various network dynamics resulting from variations in the UAV density, and speed.

Keywords—uncovered neighbor, neighbor information update, aerial relay selection, relay decision factor, unmanned aerial vehicle, flying ad hoc network

Ⅰ. INTRODUCTION

Recently, multi-hop flying ad hoc networks (FANETs) have received considerable attention because of their various advantages, such as ease of deployment, scalability, cost, and latency reduction [1], [2]. However, FANETs still encounter serious problems such as a highly dynamic network topology and the limited on-board battery of unmanned aerial vehicles (UAVs) [4]. Thus, to increase the coverage probability while reducing unnecessary packet transmissions, realizing efficient and effective relay selection is important. To resolve these issues, we propose an Uncovered Neighbor-aware Probabilistic Relay-Selection (UNPR) method that considers FANET's topological dynamics.

Ⅱ. UNPR: PROPOSED UNCOVERED NEIGHBOR-AWARE PROBABILISTIC RELAY-SELECTION METHOD

In this study, we consider broadcast transmission-based data dissemination in multi-hop tactical FANET environments. As the number of UAVs increases, it is crucial to select the optimal UAV-Rs to maximize the coverage probability while minimizing the number of unnecessary relaying transmissions. Hence, we first classify the child UAVs to differentiate between covered and uncovered neighbors. Fig. 1 presents the child UAV classification diagram. UNPR takes into consideration uncovered neighbors (shared child type-3 UAVs and unique child UAVs) as UAV-R candidates.

We define a relay decision factor (RDF) for efficient UAV-R selection while considering the child UAV characteristics. The RDF of n_i ($R(n_i)$) can be calculated by considering shared child type-3 UAVs and unique child UAVs as follows:

$$R(n_i) = \omega_{s_3} \times \frac{|N_{s_3}(n_i)|}{|N_{\mathrm{tot}}(n_i)|} + \omega_u \times \frac{|N_u(n_i)|}{|N_{tot}(n_i)|}, \tag{1}$$

where ω_{s_3} and ω_u are the weighting factors for shared child type-3 UAVs and unique child UAVs, respectively. $N_{s_3}(n_i)$ and $N_u(n_i)$ are sets of the shared child type-3 UAVs of UAV n_i and unique child UAVs of UAV n_i, respectively. From equation (1), if $R(n_i)$ is greater than or equal to the RDF threshold (R_{th}), it is determined that UAV n_i will be the UAV-R candidate for the current packet relay.

In this study, to minimize duplicate relay transmissions without reducing the coverage probability, in the proposed UNPR method, a probabilistic relay decision method is applied that takes into consideration the UAV density. UAV n_i, which becomes one of the UAV-R candidates from equation (1), can calculate its relaying probability threshold ($P^{th}(n_i)$) as follows:

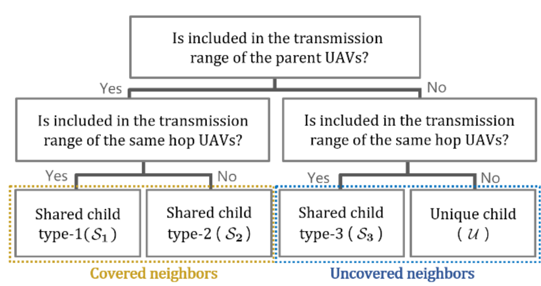

Figure 1. Child UAV classification diagram.

Table 1. TNT, CP, and EE of proposed UNPR and benchmark methods according to variations in UAV speed (v_{max} = {5, 10, 15, 25 m/s}) under 50 UAVs, $\omega_u = 0.5, \omega_s = 0.5, and\ R^{th} = 0.1$.

Methods	$v_{max} = 5\ [m/s]$			$v_{max} = 10\ [m/s]$			$v_{max} = 15\ [m/s]$			$v_{max} = 25\ [m/s]$		
	TNT	CP	EE	TNT	CP	EE	TNT	CP	EE	TNT	CP	EE
FL	305.7930	0.9944	0.1626	229.6130	0.9894	0.2154	187.2990	0.9697	0.2589	143.9400	0.9620	0.3342
PR	44.6240	0.8935	1.0012	34.7160	0.8365	1.2047	28.2960	0.7802	1.3786	22.9620	0.7515	1.6354
SFR-3	64.6840	0.9608	0.7427	52.3920	0.9512	0.9078	42.2770	0.9046	1.0699	31.4770	0.8384	1.3317
SFR-4	127.6290	0.9772	0.3828	98.3070	0.9700	0.4934	80.3930	0.9382	0.5835	60.9040	0.9025	0.7409
UNPR ($\omega_p = 1$)	36.4990	0.9861	1.3509	33.3370	0.9702	1.4552	31.1750	0.9455	1.5164	27.7280	0.9237	1.6656
UNPR ($\omega_p = 1.6$)	21.1540	0.9067	2.1431	18.3920	0.8495	2.3095	16.5180	0.7985	2.4172	14.6950	0.7627	2.5952

$$P^{th}(n_i) = \left[\omega_p \times |N_p(n_i)|\right]^{-1}. \quad (2)$$

Here, ω_p is the weighting factor for the number of parents, and $|N_p(n_i)|$ denotes the number of parent UAVs of n_i. If the randomly generated value $P(n_i) \in [0, 1]$, is less than or equal to $P^{th}(n_i)$, then UAV n_i finally becomes a UAV-R.

Ⅲ. PERFORMANCE EVALUATION

To measure the performance of the benchmark and proposed methods, we considered the Total Number of packet Transmissions (TNT), Coverage Probability (CP), and Energy Efficiency (EE) as performance metrics. Furthermore, using variations in the UAV density and UAV speed, we conducted a performance comparison of the proposed UNPR method with several benchmark methods such as Flooding (FL), Probabilistic Broadcast (PB), and Selected Fixed Relay-N (SFR-3 and SFR-4). The UNPR method's weighting factors were set to $\omega_u = 0.5, \omega_s = 0.5,$ and $R^{th} = 0.1$ in the simulation.

Fig. 2 presents the TNT, CP, and EE versus UAV density of the benchmark and proposed methods in multi-hop FANET environments. These simulation results are obtained by changing the total number of UAVs within the same-sized network from 10 to 100 to analyze the tendency according to the UAV density. UNPR (ω_p =1.6) has a slightly smaller CP than UNPR (ω_p =1), but also has a smaller TNT; therefore, the proposed UNPR (ω_p =1.6) method has the highest EE among these methods.

To evaluate the effects of different UAV speeds, we varied the maximum speeds of UAVs from 5 m/s to 25 m/s under 50 UAVs. Table. 1 presents the TNT, CP, and EE of the proposed UNPR and benchmark methods according to variations in the UAV speed. As the speed increases, the NI becomes inaccurate owing to topological variations, which cause transmission failure. The proposed UNPR (ω_p =1) method achieves a CP performance that is highly comparable to FL, while exhibiting a remarkable improvement in the EE. The RDF and probabilistic relay decision of the proposed UNPR method contribute to enhancing adaptability to environmental changes.

Ⅳ. CONCLUSIONS

In this study, we proposed a UNPR method to facilitate data dissemination in multi-hop FANETs. UNPR takes into consideration uncovered neighbors as relay candidates, and the RDF and probabilistic relay decision of the proposed UNPR contribute to reducing unnecessary packet relays without degrading the CP performance. From the simulation results, we demonstrated that UNPR outperforms the benchmark methods and is adaptable to dynamic environmental changes.

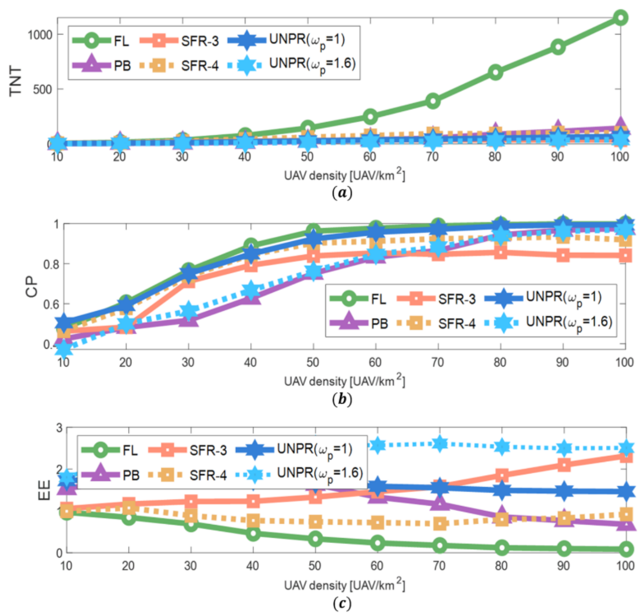

Figure 2. (a) TNT versus UAV density, (b) CP versus UAV density, and (c) EE versus UAV density of the benchmark and proposed methods in multi-hop FANET environments.

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