Complex Field Network Coding with MPSK Modulation for High Throughput in UAV Networks

Mingfei Zhao[1], and Rui Xue[1*]
[1] College of Information and Communication Engineering, Harbin Engineering University,
Harbin, 150001, China
[e-mail: zhaomingfei0825@hotmail.com, xuerui0216@hotmail.com]
[*]Corresponding author: Rui Xue

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Abstract

Employing multiple drones as a swarm to complete missions can sharply improve the working efficiency and expand the scope of investigation. Remote UAV swarms utilize satellites as relays to forward investigation information. The increasing amount of data demands higher transmission rate and complex field network coding (CFNC) is deemed as an effective solution for data return. CFNC applied to UAV swarms enhances transmission efficiency by occupying only two time slots, which is less than other network coding schemes. However, conventional CFNC applied to UAVs is combined with constant coding and modulation scheme and results in a waste of spectrum resource when the channel conditions are better. In order to avoid the waste of power resources of the relay satellite and further improve spectral efficiency, a CFNC transmission scheme with MPSK modulation is proposed in this paper. For the proposed scheme, the satellite relay no longer directly forwards information, but transmits information after processing according to the current channel state. The proposed transmission scheme not only maintains throughput advantage of CFNC, but also enhances spectral efficiency, which obtains higher throughput performance. The symbol error probability (SEP) and throughput results corroborated by Monte Carlo simulation show that the proposed transmission scheme improves spectral efficiency in multiples compared to the conventional CFNC schemes. In addition, the proposed transmission scheme enhances the throughput performance for different topology structures while keeping SEP below a certain value.

Keywords: Complex field network coding, UAV swarm, MPSK modulation, Throughput.

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1. Introduction

Remote and long-endurance unmanned aerial vehicles (UAVs) for investigation is an important application for drones [1, 2]. To accomplish more complex tasks, multiple drones as a swarm instead of one single UAV is selected for remote assignments [3, 4]. Due to the limitation of antenna and power [5, 6], UAVs cannot transmit information directly to the command and control center [7]. Therefore, UAVs employ satellites as relays to forward data when implementing remote tasks [7]. Conventional drone swarms transmit data through orthogonal channels such as time division multiple access (TDMA) [8], which occupies excessive time slots. As the increasing number of source drones and relay satellites, time slots occupied become more and more and the conventional relay schemes become increasing inefficient [9].

With the increasing complexity and diversification of wireless communication [10], to break through the bottleneck of throughput, network coding (NC) is considered as an effective solution to the data return of UAV swarms. The throughput of complex field network coding (CFNC) is higher than other NC schemes [11], such as random linear network coding (RLNC) [12], physical-layer network coding (PNC) [13] and Galois field network coding (GFNC) [14]. High throughput performance is one of requirements for 6G communications [15]. Recently, CFNC has been applied to various wireless scenarios [16], relay-based UAV cooperative system for higher throughput and achieved maximum possible diversity gain with multiple user detection. For the topology structure of $(N_s, N_r, 1)$, which means the number of source drones, relay satellites and destination are N_s, N_r and 1 respectively, CFNC attains throughput as high as 1/2 symbol per source per channel use (sym/S/CU). The transmission scheme of CFNC can be expressed in **Fig. 1**.

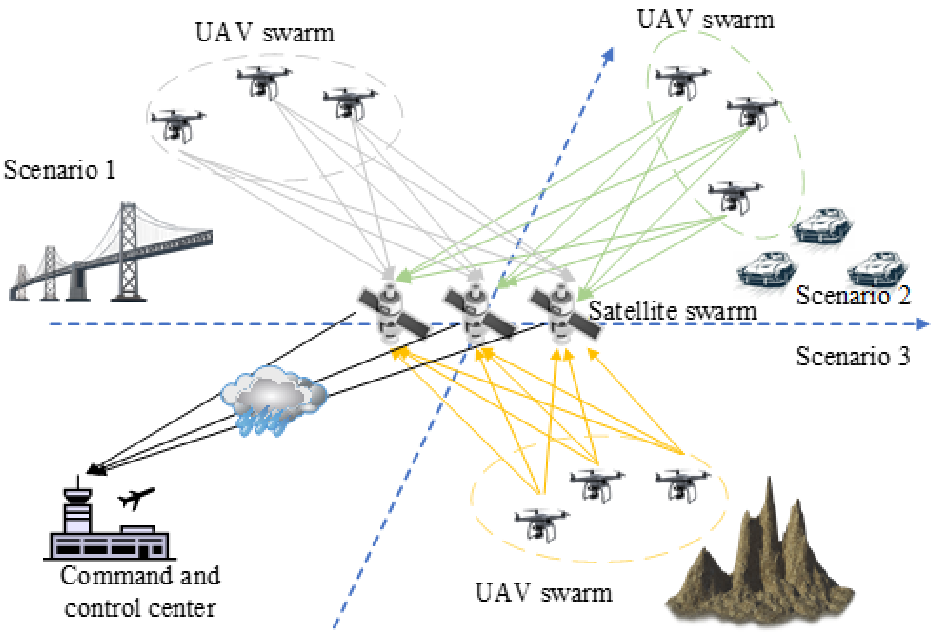

Fig. 1. Transmission scheme for UAV swarms employed by CFNC

CFNC, which was originally applied to routing in lossless wireline network, has been developed for wireless relay networks [17]. Therefore, due to the influence caused by fading channels and noises [18], the reliability of CFNC performs poorly while achieving high throughput. Therefore, the method of signal processing is an important topic for wireless communications [19]. Aiming to improve the reliability performance, CFNC in wireless networks is combined with channel coding technology, like low density parity check (LDPC) codes, and modulation, like binary phase shift keying (BPSK). Recently, Ka-band is selected for satellite communications for larger bandwidth and Ka-band is deeply affected by weather conditions [20-22]. Hence, for satellite relay wireless networks, CFNC is constantly combined with low-order coding and modulation scheme against the worst weather condition and maintain symbol error probability (SEP) below a certain value. With the increase of equipment, spectrum resources are becoming increasingly scarce [23] and determining how to adequately utilize spectrum resources is crucial for UAV networks.

Although CFNC combined with low-order coding and modulation guarantees the reliability performance, it leads to a waste of spectrum resource when the weather condition becomes better. To adequately utilize spectrum resource and satisfy different requirements of different transmission, a CFNC transmission scheme combined with different modulations is proposed in this paper. Better utilization of the increasingly scarce satellite spectrum resources is of high research value. On the one hand, CFNC combined with low-order modulation scheme is applied to UAV networks for quality of service (QoS) requirement; On the other hand, CFNC combined with high-order modulation scheme is applied to UAV networks for throughput requirement. Satellite relay selects information transmission schemes according to current channel state and different transmission requirements and then switches when the requirements change. Compared to conventional CFNC schemes, which is combined with constant coding and modulation, the proposed CFNC transmission scheme improves spectral efficiency and adequately utilizes bandwidth resource.

The rest of this paper is organized as follows: Section 2 introduces the CFNC information transmission scheme for UAV networks. Section 3 presents a CFNC transmission scheme combined with different modulations for higher spectral efficiency. Simulation results and analysis are demonstrated in Section 4. The conclusion is expressed in Section 5.

2. CFNC for UAV Networks

Conventional CFNC transmission scheme for UAV networks has enhanced throughput performance by reducing transmission time slots. Conventional CFNC schemes are combined with constant coding and modulation for UAV networks. Topology structure and information transmission process are two main factors affecting performance of CFNC.

2.1 Topology Structure

The topology structure for conventional schemes and CFNC schemes applied to UAV networks is expressed in **Fig. 2** and **Fig. 3**. The structure of UAV networks can be divided into regular structure and irregular structure. When the communication links between UAV swarms and satellite swarms, communication links between satellite swarms and command and control center all exist, we define it regular structure. Adversely, we define it irregular structure. Due to the stable position of satellites, we legitimately consider that the communication links between each satellite and the command and control center steadily exist. However, due to the obstacles and the flexibility of drones, the communication links between UAVs and satellites are seriously influenced. Therefore, UAV swarms transmit information in the form of irregular structure in general.

As shown in Fig. 2 and Fig. 3, conventional schemes occupy $(N_s+1)N_r$ time slots and the throughput can be expressed as $1/(N_s+1)N_r$ (sym/S/CU) for $(N_s,N_r,1)$ structure. CFNC schemes occupy 2 time slots and the throughput can be expressed as 1/2 (sym/S/CU) for $(N_s,N_r,1)$ structure. CFNC schemes for UAV networks obviously improve the throughput performance as high as 1/2 (sym/S/CU) and the advantages of throughput performance become more evident as the increasing number of source UAVs and relay satellites. In addition, the throughput performance of CFNC is not influenced by the number of source nodes and relay nodes, which is the most obvious difference between CFNC and other NC schemes, such as RLNC, PNC and GFNC.

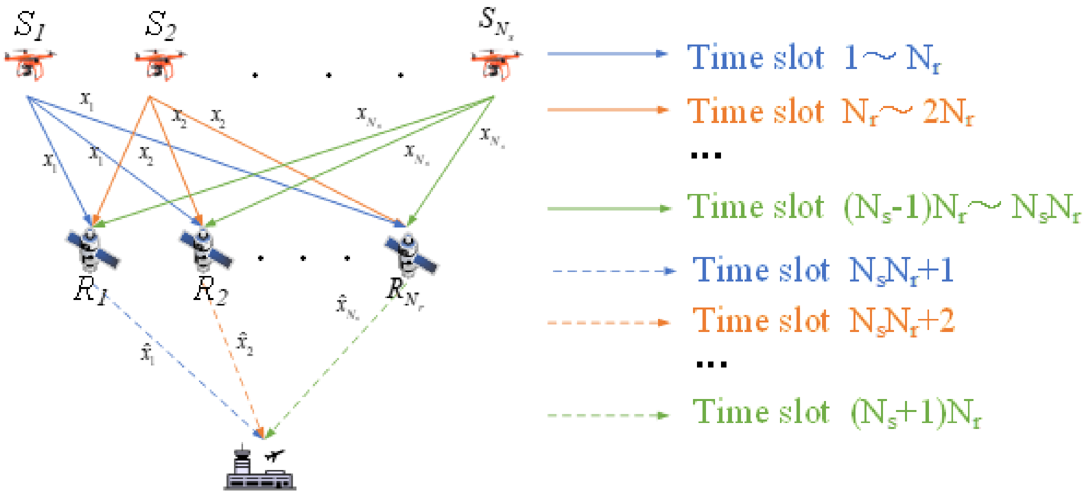

Fig. 2. Topology structure for conventional schemes applied to UAV networks

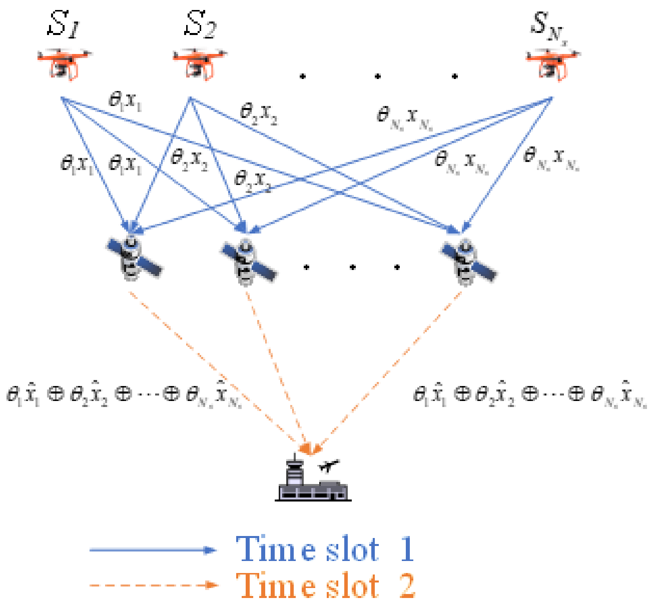

Fig. 3. Topology structure for CFNC schemes applied to UAV networks

CFNC scheme processes the modulated symbol data. After the bit information is coded and modulated, the symbol data from the source UAVs is multiplied by the CFNC coefficient θ. The symbol data from source UAV S_1 to S_{N_s} can be represented as $(x_1, x_2, \cdots, x_{N_s})$. In the first time slot, all UAVs transmit data to each satellite relay and the received data can be expressed as $(\theta_1 x_1, \theta_2 x_2, \cdots, \theta_{N_s} x_{N_s})$. After the detections and demodulations, satellite relays obtain the estimated symbols $(\hat{x}_1, \hat{x}_2, \cdots, \hat{x}_{N_s})$, which are multiplied by θ and transmitted as $(\theta_1 \hat{x}_1, \theta_2 \hat{x}_2, \cdots, \theta_{N_s} \hat{x}_{N_s})$. The information transmission process of CFNC is presented in next section.

2.2 Information Transmission Scheme

As depicted in **Fig. 3**, UAVs send data to each satellite in the first time slot and the satellites forward data to the command and control center in the second time slot. Bit information from S_1 to S_{N_s} can be expressed as $(s_1, s_2, \cdots s_{N_s})$. For conventional CFNC schemes, $(s_1, s_2, \cdots s_{N_s})$ are processed by constant coding and modulation and the symbol information $(x_1, x_2, \cdots, x_{N_s})$ can be obtained. After passing through the fading channel between UAVs and satellites, the information received at relay satellite R_j can be expressed as follows

$$\begin{aligned} y_{SR_j} &= h_{S_1R_j}\theta_1 x_1(t) + \cdots + h_{S_{N_s}R_j}\theta_{N_s} x_{N_s}(t) + n_{SR_j}(t) \\ &= \boldsymbol{\theta}_S^T \mathbf{H}_{SR_j}\mathbf{x}(t) + n_{SR_j}(t) \end{aligned} \tag{1}$$

where $h_{S_1R_j}$ represents the channel coefficient between source S_1 and relay R_j. $\mathbf{H}_{SR_j}$ indicates channel coefficient between UAV swarm and relay R_j and $\mathbf{H}_{SR_j}$ can be expressed as follows

$$\mathbf{H}_{SR_j} = diag(h_{S_1R_j}, h_{S_2R_j}, \cdots, h_{S_{N_s}R_j}) \tag{2}$$

$\boldsymbol{\theta}_S^T$ denotes the CFNC coefficient and can be expressed as follows

$$\boldsymbol{\theta}_S^T = [\theta_1, \theta_2, \cdots, \theta_{N_s}] \tag{3}$$

where $\theta_i = e^{j\pi(4n-1)(i-1)/(2N_s)}$ when $N_s = 2^k$ and $\theta_i = e^{j\pi(6n-1)(i-1)/(3N_s)}$ when $N_s = 3\times 2^k$ and n is the nth row in Vandermonde matrix. After receiving signals from UAVs, satellite relays process signals by maximum likelihood (ML) detections. The estimated symbol value $\hat{x}_j(t)$ can be represented as follows

$$\hat{\mathbf{x}}_j(t) = \arg\min_{x(t)} \left\| y_{SR_j}(t) - \boldsymbol{\theta}_S^T \mathbf{H}_{SR_j}\mathbf{x}(t) \right\| \tag{4}$$

Conventional CFNC schemes process the symbol information without decoding and demodulating. The estimated symbol value $\hat{\mathbf{x}}_j(t)$ is processed by the link-adaptive scalar α and then sent to command and control center. In the second time slot, the CFNC coefficient $\boldsymbol{\theta}_R$ can be represented as follows

$$\boldsymbol{\theta}_R^T = [\theta_1^{'}, \theta_2^{'}, \cdots, \theta_{N_s\times N_r}^{'}] \tag{5}$$

where $\theta_i = e^{j\pi(4n-1)(i-1)/(2n)}$ when $N_r \times N_s = 2^k$ and $\theta_i = e^{j\pi(6n-1)(i-1)/(3n)}$ if $N_r \times N_s = 3\times 2^k$. The number of source nodes and relay nodes determine the size and design of $\theta_{R_j}^T$.

After the data passes through the fading channel of satellite downlink, the received signal at command and control center can be denoted as follows

$$y_{R_jD}(t) = \sqrt{\alpha_j} h_{R_jD} \boldsymbol{\theta}_R^T \hat{x}_j(t) + n_{R_jD},\ j = 1, \cdots, N_r \tag{6}$$

and the estimated symbol $\hat{\mathbf{x}}_j(\mathrm{t})$ is shown as follows

$$\hat{\mathbf{x}}_j(\mathrm{t}) = [\hat{x}_j^T(1), \cdots, \hat{x}_j^T(N_r)]^T \tag{7}$$

where h_{R_jD} represents the channel coefficient between relay R_j and destination and n_{R_jD} is the additive white Gaussian noise (AWGN). After two CUs transmissions, ML detection is selected to recover the symbol value, the estimated value $\hat{x}_D$ result at command and control center is as follows

$$\hat{\mathbf{x}}_D(t) = \arg\min \left\{ \sum_{t=1}^{N_r} \sum_{j=1}^{N_r} \left\| y_{R_jD}(t) - \sqrt{\alpha_j} h_{R_jD} \boldsymbol{\theta}_R^T \mathbf{x}'(t) \right\|^2 \right\} \tag{8}$$

where $x'(t)$ is indicated as follows

$$\mathbf{x}'(t) = [x^T(1), \cdots, x^T(N_r)]^T \tag{9}$$

After the estimated symbol $\hat{\mathbf{x}}_D(t)$ is obtained, the bit information can be recovered by decoding and demodulation. As demonstrated above, conventional CFNC schemes for UAV networks processes the symbol information. Relay satellites forward symbol information without decoding and demodulation. To guarantee the quality of transmission, conventional CFNC schemes are combined with low-order coding and modulation method. However, convention CFNC scheme will result in a waste of spectral efficiency when the channel conditions are better. Therefore, determining how to satisfy different transmission requirements and adequately utilize the limited resources of satellites is the key for UAVs networks.

3. CFNC for Higher Spectral Efficiency

For UAVs networks, reducing time slots and improving spectral efficiency are two primary methods enhancing throughput. In multi-node relay-based communication systems, CFNC occupies the least time slots in theory. Therefore, CFNC combined with more efficient modulation schemes is an effective method to satisfy higher throughput requirements. CFNC transmission scheme with different modulations is shown in **Fig. 4**. The objects of processing information are UAVs, satellites and command and control center.

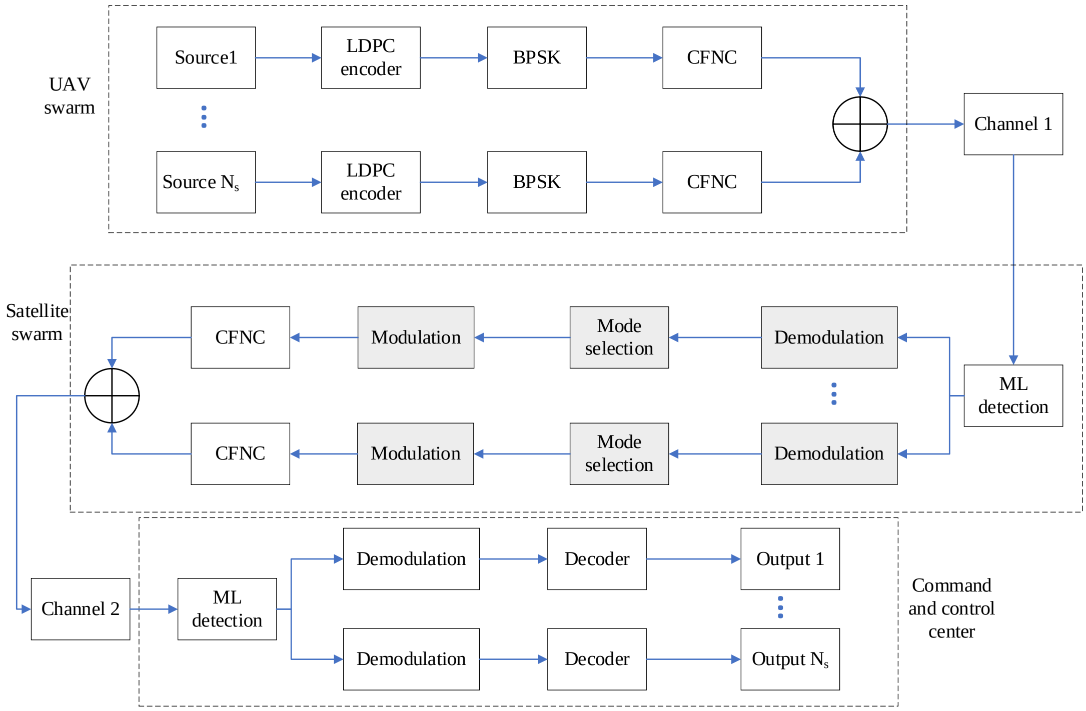

Fig. 4. CFNC transmission scheme with different modulations

The process of information at drones for the proposed scheme has no difference from conventional CFNC schemes. The bit information is processed by LDPC code and BPSK modulation and the symbol information is obtained. After that, symbol information is multiplied by CFNC coefficient and transmitted to satellite relays. In addition, the process of data at command and control center includes ML detection, demodulation and decoding. The way of demodulation depends on the mode modulation of relay selection. The key to the proposed transmission scheme is the process of information at satellite relays, which includes working process, scheme selection and switching algorithm.

3.1 Working Process

Different from conventional CFNC relay schemes, the proposed CFNC scheme reselects the modulation mode for the coded information according to the current channel conditions. Considering that the code rate has limited effect on spectrum efficiency, to reduce the complexity, relay satellites will not decode and recode information. As mentioned above, employing Ka-band for information transmission is the development tendency of satellite communications. Communications in Ka-band are seriously influenced by weather conditions, especially rain attenuations. Therefore, selecting different modulation modes according to different channel conditions can improve information transmission efficiency. As shown in **Fig. 5**, the working process is as follows:

(1) UAV swarms return information to satellite relays.
(2) After receiving information from UAVs, relay satellites send training sequences to command and control center for channel estimation.
(3) Training sequences are returned to the relay satellites.
(4) The received training sequences at satellite relays are employed for channel estimations, which express the current channel conditions.

(5) According to the channel conditions, relay satellites select modulation scheme and process the coded data.
(6) Information downloads.

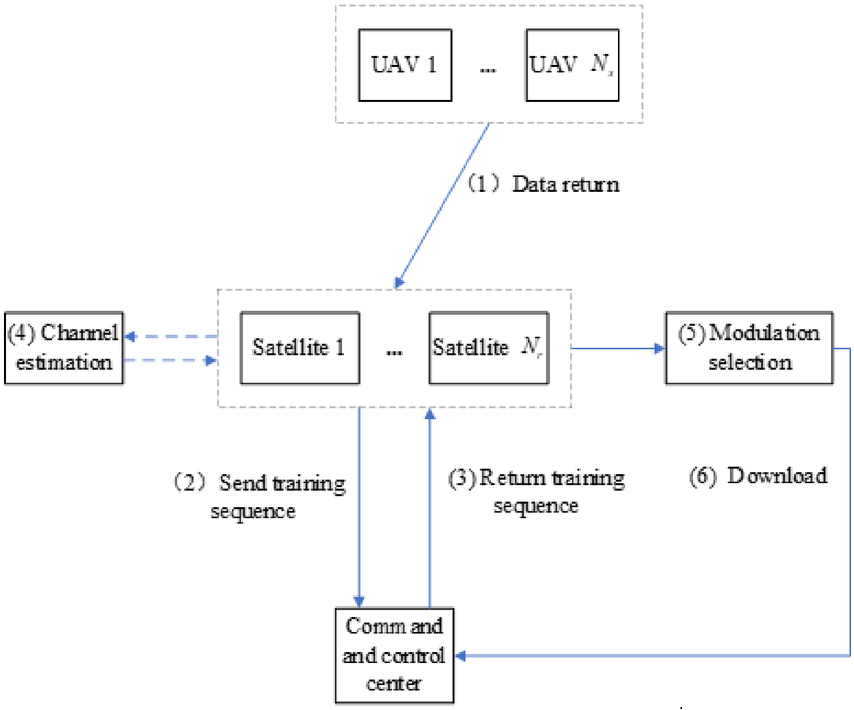

Fig. 5. Flow chart of working process

E_b / N_0, which means the signal to noise ratio, is selected on behalf of channel conditions. The estimated value of E_b / N_0 determines the scheme switching. The performance of the proposed scheme will be affected when the estimated value of E_b / N_0 is inaccurate. If the actual value of E_b / N_0 is larger than the estimated value, the throughput performance cannot be improved; If the actual value of E_b / N_0 is smaller than the estimated value, the quality of transmission cannot be guaranteed. In addition, the transmitter and the receiver are commonly not cooperative in actual communication scenarios. Therefore, we adopt $\mathrm{M_2M_4}$ algorithm for channel estimations [24]. When the estimated value of E_b / N_0 is obtained, we can select modulation mode for relay satellites.

3.2 Scheme Selection

Modulation schemes are selected for the information transmission of satellite downlink. Therefore, the selection of modulation is employed by digital video broadcasting satellite second generation (DVB-S2). We adopt low density parity check (LDPC) code with 1/2 code rate as coding scheme. Conventional CFNC scheme for UAV networks employs BPSK as modulation scheme [9]. To further improve throughput performance, we select 8 phase shift keying (8PSK) 16 phase shift keying (16PSK) for UAV networks. In addition, we select target SEP algorithm for scheme switching. Limited by the target SEP value, switching thresholds for modulation selections can be derived. Different target SEP limits lead to different switching thresholds. We adopt 10^{-4} as the target SEP value. The modulation schemes and spectral efficiency are depicted in **Table 1**.

Table 1. Applications in each class

Modulation schemes	Modulation mode	Code mode	Code rate	Spectral efficiency
Modulation scheme 1	BPSK	LDPC	1/2	0.5
Modulation scheme 2	8PSK	LDPC	1/2	1.5
Modulation scheme 3	16PSK	LDPC	1/2	2

The spectral efficiency of above three modulation schemes increases gradually. The proposed CFNC scheme adequately utilizes the power and spectrum resource by switching different modulations while maintaining SEP below target SEP value. Throughput performance can be represented as follows

$$T = R(1 - P_b) \tag{10}$$

where T indicates throughput for single transmission, R indicates transmission rate of satellites and P_b indicates the frame error rate. CFNC scheme improves throughput performance by reducing time slot and the proposed transmission scheme further enhances throughput performance by increasing spectral efficiency. Time slots occupied and spectral efficiency are two primary factors affecting throughput performance when the transmission rate is fixed. Through scheme switching, during a certain transmission time, the total amounts of throughput can be represented as follows

$$T' = \sum_{i=1}^{k} C_i \Delta t_i \tag{11}$$

where k represents total numbers of modulation schemes, i represents the ith modulation scheme, C_i represents the spectral efficiency of ith modulation scheme and Δt_i represents the total time UAVs work in the ith modulation schemes. Assuming that the E_b / N_0 range of satellite operation is 0-20 dB and satellites work same time in each value of E_b / N_0. The proposed CFNC scheme obtains 2.08 times compared to conventional CFNC schemes. Therefore, CFNC with different modulations improve the throughput obviously compared to conventional CFNC schemes for UAV networks. The premise of improving the throughput of information transmission is based on accurate scheme switching algorithm. An efficient algorithm can not only ensure prompt switching of modulation scheme with high spectral efficiency, but guarantee the quality of transmission.

3.3 Switching Algorithm

The switching algorithm, which directly affects the performance of transmission, is an important part in CFNC schemes for UAV networks. The strategy of switching algorithm is shown in **Fig. 6**. A and B are threshold values satisfying $A < B$. Scheme 1 ~ scheme 3 are three alternative schemes and the spectral efficiency increases in turn. Therefore, three E_b / N_0 ranges are obtained as $(0, A]$, $(A, B]$ and (B, ∞) for each scheme.

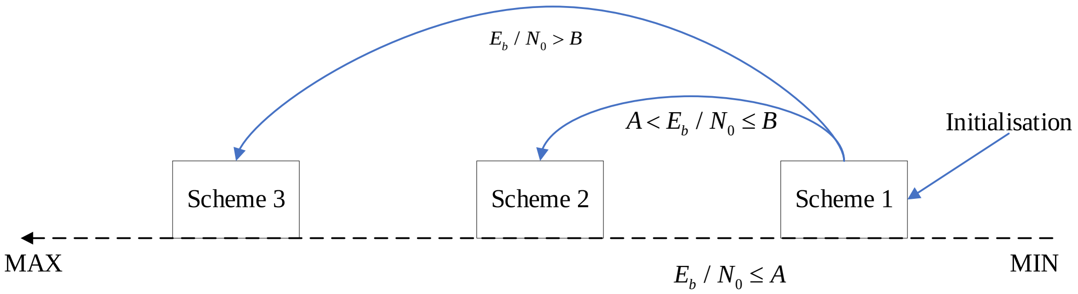

Fig. 6. Switching algorithm

The commonly used switching algorithms include switching algorithm based on average E_b / N_0 values, switching algorithm based on minimum E_b / N_0 values and switching algorithm based on variance correction. Switching algorithm based on average E_b / N_0 values and switching algorithm based on minimum E_b / N_0 values are simple and low complexity, which are commonly used switching algorithms. For switching algorithm based on average E_b / N_0 values, we set a frame number N and the average E_b / N_0 values of received N -frame information is considered as the reference E_b / N_0 value of switching. Assuming that the received values of E_b / N_0 are $(\gamma_1, \gamma_2, \gamma_3, \cdots, \gamma_N)$, the reference E_b / N_0 value can be expressed as follows

$$\gamma_V = \frac{1}{N}\sum_{n=1}^{N}\gamma_n \tag{12}$$

Switching algorithm based on average E_b / N_0 values is easy to implement and the stability of the system is effectively improved due to adopting average values as reference threshold. However, when the value of E_b / N_0 approaches to the threshold, SEP of the transmission may become high because sharp changes of channel make values of E_b / N_0 for different frames are different. In addition, when channel conditions change rapidly, satellite may select higher order modulation by mistake and result in higher SEP. For switching algorithm based on minimum E_b / N_0 values, we set a frame number N and calculate E_b / N_0 value of each frame. We adopt the minimum E_b / N_0 value as reference E_b / N_0 value. Assuming that the E_b / N_0 of each frame for received data are $(\gamma_1, \gamma_2, \gamma_3, \cdots, \gamma_N)$, the reference value of switching algorithm based on minimum E_b / N_0 values can be represented as follows

$$\gamma_M = \min\{\gamma_1, \gamma_2, \gamma_3, \cdots, \gamma_N\} \tag{13}$$

Switching algorithm based on minimum E_b / N_0 values is the easiest algorithm to implement of the above three algorithms. Since the E_b / N_0 value of the worst channel condition in all received data is selected as the reference E_b / N_0 value, the actual received E_b / N_0 value of other frames must be higher than the reference E_b / N_0 value. Therefore, the selected modulation scheme is the lowest order modulation scheme. In this case, SEP performance of the system must be lower than the target bit error rate, but part of the throughput performance is sacrificed. For switching algorithm based on variance correction, we correct the average E_b / N_0 values of each frame. The corrected value of E_b / N_0 can be expressed as follows

$$\gamma_r = u_r - \sigma_r \tag{14}$$

where σ_r is standard deviation of received E_b / N_0 value for each frame signal and σ_r can be represented as follows

$$\sigma_r = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(\gamma_n - u_r)^2} \tag{15}$$

It can be seen that when the channel state is poor, the correction of average SNR is larger, otherwise the correction is less. Compared to average SNR algorithm, the switching algorithm based on variance correction SNR can improve the throughput performance to some extent. However, the error of channel state information estimation will have a non-negligible impact on the proposed scheme, especially for the switching algorithm of the proposed scheme. Specifically, when the estimated value of downlink E_b / N_0 is less than the actual value, the switching threshold of the scheme is less than the accurate value. In this case, the scheme with higher spectral efficiency is switched when the SEP cannot be guaranteed, which will lead to the improvement of spectral efficiency, but the SEP cannot be guaranteed to be lower than the target value. On the contrary, the higher estimated value will lead to a slightly lower spectral efficiency, but ensure that the SEP is lower than the target value. The designed scheme in this paper prefer to select a higher throughput scheme under the premise of ensuring that SEP is lower than the target value. Therefore, under the premise of target SEP, we select the switching algorithm based on variance correction SNR as the switching algorithm. At the same time, shift threshold technique is used to reduce the influence of SNR estimation error on system performance.

4. Simulation Results and Analysis

The throughput performance and SEP performance of CFNC scheme with MPSK modulation are tested in this section. Monte Carlo simulations for software are performed to evaluate the capability of UAV networks. The proposed transmission scheme is compared to conventional CFNC transmission scheme for UAV networks in [9]. The information from UAVs pass through two channels, channel between UAV swarm and satellite swarm and channel between satellite swarm and command and control center. The information propagation characteristics conform to Ka-band channel model, which is demonstrated in [24]. Ka-band fading channel is a non-frequency selective channel and many factors lead to signal fading in Ka-band such as rain, thunders, clouds and atmosphere, and rain attenuation. Rain attenuation is the most serious factor among them. As depicted in [24], The digital modulation signal can be seen as a combination of two segments, the fading channel caused by the frequency independent complex multiplicative interference and additive white gaussian noise (AWGN). The fading factor of the Ka-band channel is $C(t) = \alpha \exp(j\theta)$ and the AWGN is $z(t)$, where α and θ express the envelope and the phase of the equivalent lowpass channel.

Topology structure of UAV networks is a key factor affecting system performance. When the number of source UAVs is fixed, SEP performance becomes lower as the number of relay satellites increase because more relay satellites provide more diversity gain for received information. When the number of relay satellites is fixed, SEP performance becomes higher as the number of source UAVs increase because more source information leads to more multiuser interference. To comprehensively verify the improvement of throughput performance of the proposed scheme, we validate SEP performance of different topology structures.

The binary information frame length is set as 600 bits. For LDPC code, the check matrix $\mathbf{H}$ is constructed by Quasi-Cyslic (QC) algorithm and the generated matrix $\mathbf{G}$ is obtained by Gaussian elimination. Moreover, belief propagation (BP) algorithm is selected for LDPC decoding. Transmit power of each UAV is set to normalized power 1 in simulations. Soft demodulation is adopted for MPSK signal in relay satellites and command and control center. Frame numbers for simulations are set to 50000 and the iteration number is set to 20.

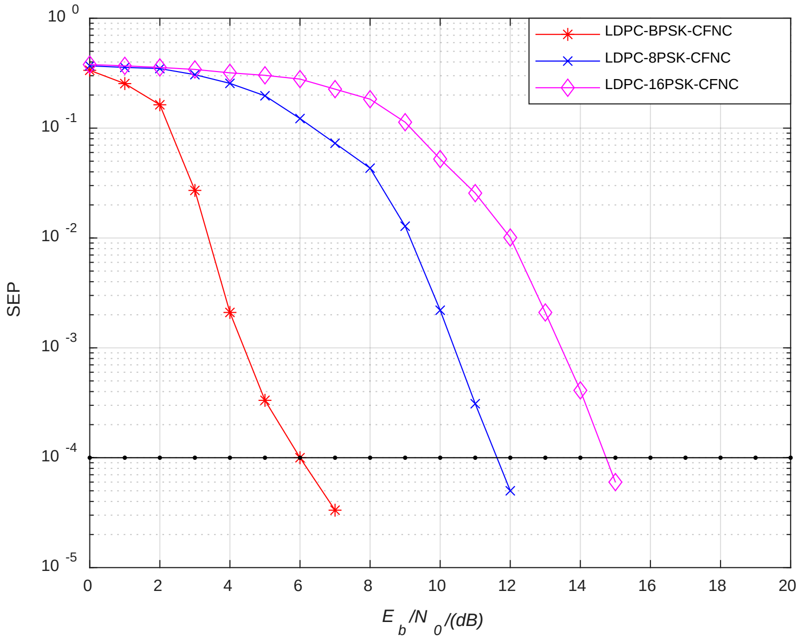

Fig. 7. SEP performance of different modulations for [2, 3, 1]

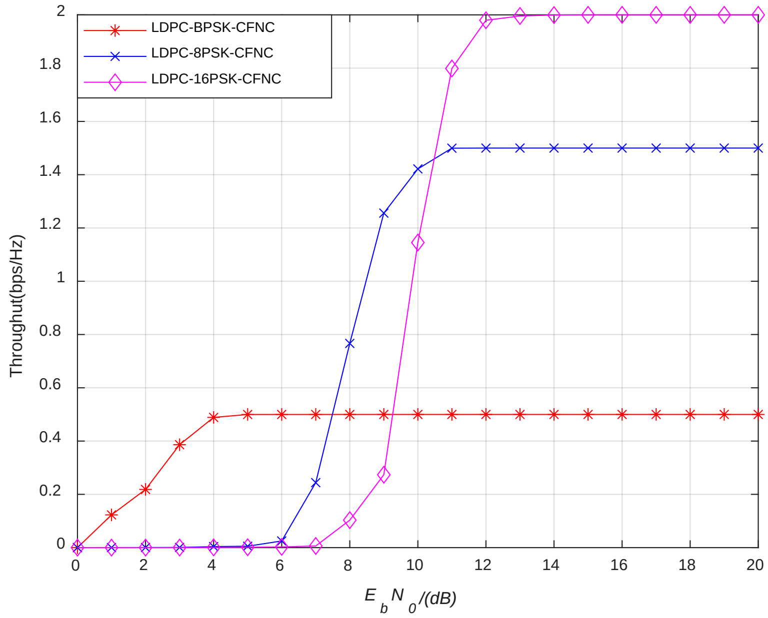

Fig. 8. Throughput performance of different modulations for [2, 3, 1]

SEP performance and throughput performance of different modulations for topology structure of [2, 3, 1] are depicted in **Fig. 7** and **Fig. 8**. The horizontal information in **Fig. 7**, **Fig. 8**, **Fig. 9** and **Fig. 10** represents E_b / N_0. E_b denotes the energy per bit of information, and N_0 denotes the noise power spectral density. The lengthways information of **Fig. 7** and **Fig. 9** expresses SEP and the lengthways information of **Fig. 8** and **Fig. 10** expresses throughput performance. We set target SEP value as 10^{-4}. LDPC with BPSK, 8PSK and 16PSK all can achieve target SEP 10^{-4} when the value of E_b / N_0 is below 20 dB. When the value of E_b / N_0 is below 11.5 dB, the SEP and throughput performance of the proposed scheme is equal to conventional CFNC scheme. However, when the value of E_b / N_0 is greater than 11.5 dB, the throughput performance of proposed scheme increases in multiples compared to conventional CFNC schemes. For instance, when the value of E_b / N_0 is 16 dB, we select LDPC+16PSK combined with CFNC. The throughput performance is 4 times to conventional CFNC schemes. The switching method for topology structure of [2, 3, 1] and [3, 3, 1] is shown in **Table 2**.

Table 2. Switching method for topology structure of [2, 3, 1] and [3, 3, 1]

E_b / N_0(dB) **for [2, 3 ,1]**	E_b / N_0(dB) **for [3, 3 ,1]**	**Modulation**	**Spectral efficiency**
$E_b / N_0 \le 11.5$	$E_b / N_0 \le 13$	BPSK	0.5
$11.5 < E_b / N_0 \le 15$	$13 < E_b / N_0 \le 16$	8PSK	1.5
$E_b / N_0 > 15$	$E_b / N_0 > 16$	16PSK	2

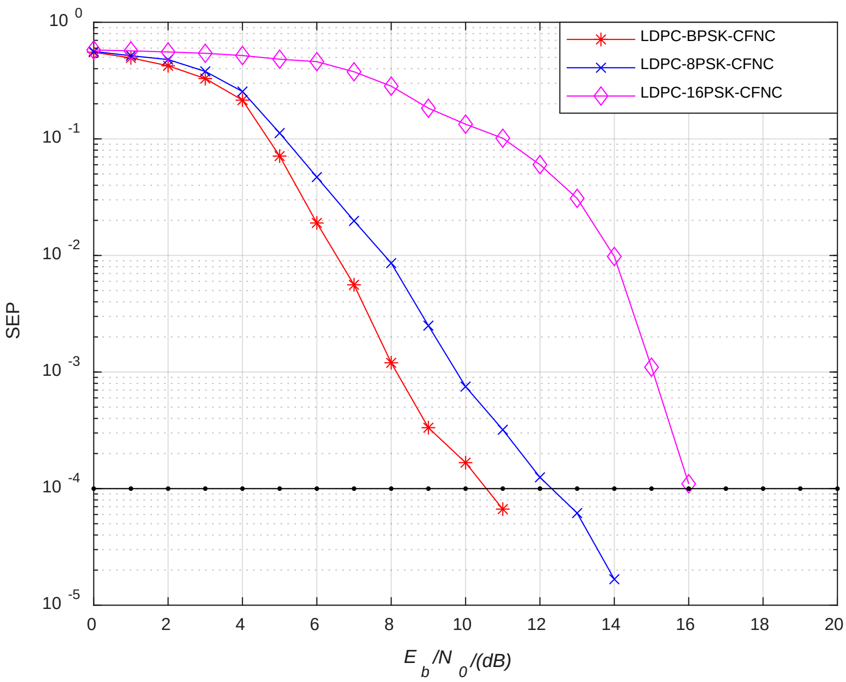

Fig. 9. SEP performance of different modulations for [3, 3, 1]

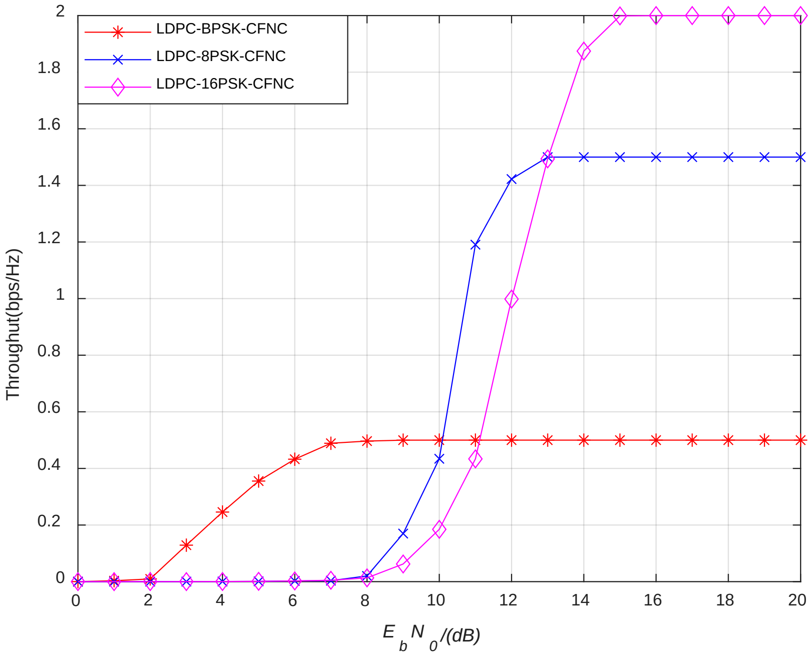

Fig. 10. Throughput performance of different modulations for [3, 3, 1]

For topology structure of [3, 3, 1], switching method also follows target SEP algorithm. Under the premise that the SEP is below 10^{-4}, the proposed transmission scheme increases throughput in multiples when the value of E_b / N_0 is more than 13 dB. For instance, when the value of E_b / N_0 is 14 dB, we select LDPC+8PSK combined with CFNC for transmission. The throughput performance is 3 times to conventional CFNC scheme. Assuming that the range of E_b / N_0 for transmission is 0 ~ 20 dB and the occupancy time of each E_b / N_0 value is the same, the proposed scheme attains 2.1 times for [2, 3, 1] topology structure and 1.9 times to [3, 3, 1] topology structure. It can be seen that the proposed transmission improves spectral efficiency and throughput performance for different topology structures of UAV networks compared to conventional CFNC transmission scheme.

5. Conclusions

In this paper, we propose a high throughput transmission scheme based on CFNC with MPSK modulation for UAV networks. Conventional CFNC transmission scheme for UAV networks improve throughput by reducing time slots. However, it leads to a waste of spectrum resource when the weather conditions are better. To further improve throughput performance, we adopt CFNC combined with MPSK modulation for different weather conditions. While keeping SEP below 10^{-4}, we select high-order modulation when weather condition is better and select low-order modulation when weather condition is worse. CFNC combined with MPSK modulation can not only occupy the least time slots, but also adequately utilize spectral efficiency. Simulation results show that the proposed transmission scheme obtains 2.1 times throughput performance for [2, 3, 1] topology structure and 1.9 times throughput performance for [3, 3, 1] topology structure.

From a theoretical point of view, the efficiency of communication between UAVs and satellites can also be improved with the similar schemes proposed in this paper. However, considering the reasons for the size of the UAV and limited airborne resources, the proposed transmission scheme is not applied to the communication links between UAVs and satellites. For future work, we can design more code and modulation approach with high spectral efficiency and further divide E_b / N_0 value into more intervals. Monitoring information from drones will increase rapidly in the future and the requirements for high throughput transmission scheme will be increasingly pressing. Therefore, the proposed CFNC transmission scheme will play more critical role in various applications.

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Mingfei Zhao received the B.E. degree in communication engineering from Harbin Engineering University, Harbin 150001, China, in 2017. He is currently pursuing the Ph.D. degree in information & communication engineering from Harbin Engineering University, Harbin 150001, China. His research interests include satellite communication and satellite navigation, adaptive transmission technology high spectral efficiency modulation and spread spectrum communication technology.

Rui Xue received the M.S. and Ph.D. degrees in communication engineering and information & communication engineering from Harbin Engineering University, Harbin 150001, China, in 2006, and 2009, respectively. Since July 2003 he has been with the College of Information & Communication Engineering, Harbin Engineering University. From July 2011 to July 2012, he was an academic visitor in Nonlinear Signal Processing Lab., University of Melbourne, Australia. He is currently an associate professor with the College of Information & Communication Engineering, Harbin Engineering University, Harbin 150001, China. His research interests are the area of radio mobile communication systems, satellite communication systems and satellite navigation and positioning, and include error-correcting codes, high spectral efficiency modulation, coded modulation, iterative decoding and detection and so on.