A Novel Active User Identification Method for Space based Constellation Network

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Summary
Space based constellation network is a kind of ad hoc network in which users are self-organized without center node. In space based constellation network, users are allowed to enter or leave the network at any given time. Thus, the number of active users is an unknown and time-varying parameter, and the performance of the network depends on how accurately this parameter is estimated. The so-called problem of active user identification, which consists of determining the number and identities of users transmitting in space based constellation network is discussed and a novel active user identification method is proposed in this paper. Active user identification code generated by transmitter address code and receiver address code is used to spread spectrum. Subspace-based method is used to process received signal and judgment model is established to identify active users according to the processing results. The proposed method is simulated under AWGN channel, Rician channel and Rayleigh channel respectively. Numerical results indicate that the proposed method obtains at least 1.16dB E_b/N_0 gains compared with reference methods when miss alarm rate reaches 10^{-3}.
Keywords:
Active user identification; Space based constellation network

1. Introduction

Space based constellation network is a kind of self-organized network, in which users transmit directly to each other without center node. Most users in space based constellation network operate under the hypothesis that the number of active users is an known and fixed parameter [1-2]. This is not the case in the real circumstance in which users can enter or leave the network at any time instant. Not accounting for the inactivity of some of the users leads to performance degradation[3-4] that aggravates as the difference between the real number of active users and the number of active users considered by the receiver increases.

In order to solve this problem many methods have been proposed by researchers in recent years. A method based on random set theory is advocated in literature [5] which has good performance but high complexity. To address this problem, literature [6] uses tree search technique to reduce the complexity. Different from random set theory-based method, literature [7] proposes a per-survivor processing method similar to Viterbi algorithm and two particle filtering based methods to identify active users which are all based on traditional probabilistic theory. Unlike the above probabilistic methods, literature [8] proposes a deterministic method based on algebraic theory to identify active users within a certain delay by designing a protocol sequence with good inter-correlation property.

All the methods introduced above have high miss alarm rate in low SNR. Therefore we propose a novel active user identification method for space based constellation network in this paper. Transmitter-receiver based active user identification code is generated to spread spectrum. A subspace-based method is adopted by receiver to process the received signal, and a judgment model is established to identify active users according to the processing results. Simulation results show that the proposed method outperforms the reference methods under different channels especially in low SNR.

2. Spectrum spreading and transmission coordination

In order to construct spectrum spreading code, two codes w and p are assigned to each user. w is called transmitter address code which is Walsh code and p is called receiver address code which is M sequence. The Walsh code table and the M sequence table are stored in each user with user number as the index of two tables. Suppose user 1 intends to transmit to user 2, before transmission user 1 searches Walsh code table to get w_1, at the same time searches M sequence table to get p_2. And then user 1 generates transmitter-receiver based active user identification code v_{12} shown in Eq. (1) as spectrum spreading code. Since Walsh codes have strong orthogonality and M sequences have strong autocorrelation, using Walsh codes and M sequences to construct v_{12} enhances the ability to resisting multiple access interference and inter-symbol interference. Meanwhile, data packet doesn't need to contain the address information of destination user in its header with v_{12} being used as spectrum spreading code, so that the energy consumption of user 2 is reduced due to avoiding extracting the address information of destination user from packet header.

$$v_{12} = w_1 \oplus p_2 \quad (1)$$

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In order to coordinate the behavior of each user, we assume each user is either in "Listen" state ("L" for short) or "Possibly Transmit" state ("PT" for short) in each symbol interval. When user is in "L" state, it can only receive signal; when user is in "PT" state, it can only transmit signal with a certain probability. The state of user is controlled by a scheduling table which is generated by pseudo random sequence generator. All users generate its scheduling table with a same generation polynomial and with the user number as initial state. User 1 generates the scheduling tables of all users and finds a symbol interval in which user 1 is in "PT" state while user 2 is in "L" state, and if there are α users in the network that are also in "PT" state, then user 1 transmits with probability $\min\{\gamma/(\alpha+1),1\}$ in which γ is a parameter that can be adjusted. The use of scheduling table can avoid network congestion and at the same time reduce energy consumption of user 2.

3. Novel active user Identification method

Consider an ad hoc network with Q users who transmit synchronously over an AWGN channel. Assuming that there are H active users transmitting at the current symbol interval. User 2 that in "L" state can receive all the packets transmitted in the current symbol interval, and the purpose of active user identification for user 2 is to identify the packets transmitted to itself from the received packets. The received signal $r(t)$ can be expressed in vector form

$$\boldsymbol{r} = \sum_{h=1}^{H} \boldsymbol{y}_h + \boldsymbol{n} \tag{2}$$

where $\boldsymbol{y}_h=[\beta_0^h \beta_1^h \dots \beta_{N-1}^h] \in \{\pm 1\}^N$ is the spectrum spreading code of the hth active user with length N. $\boldsymbol{n} \in \mathrm{R}^N$ denotes AWGN vector.

Since spectrum spreading codes are orthogonal to each other, the auto-covariance matrix of $\boldsymbol{r}$ can be written as

$$\boldsymbol{CovR} = \mathrm{E}\{\boldsymbol{r}\boldsymbol{r}^{\mathrm{T}}\} = \boldsymbol{S}\boldsymbol{S}^{\mathrm{T}} + \sigma^2 \mathrm{I}_N \tag{3}$$

where $\boldsymbol{S}=[\boldsymbol{y}_1,\boldsymbol{y}_2,\dots,\boldsymbol{y}_H] \in \mathrm{R}^{N\times H}$ .Let set $A=\{\boldsymbol{y}_1,\boldsymbol{y}_2,\dots,\boldsymbol{y}_H\}$.Eigenvalue decomposition of $\boldsymbol{CovR}$ is performed as

$$\begin{aligned} \boldsymbol{CovR} &= \boldsymbol{U}\boldsymbol{\Lambda}\boldsymbol{U}^{-1} \\ &= \boldsymbol{U}\boldsymbol{\Lambda}\boldsymbol{U}^{\mathrm{T}} \\ &= [\boldsymbol{U}_{\mathrm{s}} \ \ \boldsymbol{U}_{\mathrm{n}}]\begin{bmatrix} \boldsymbol{\Lambda}_{\mathrm{s}} & 0 \\ 0 & \boldsymbol{\Lambda}_{\mathrm{n}} \end{bmatrix}\begin{bmatrix} \boldsymbol{U}_{\mathrm{s}}^{\mathrm{T}} \\ \boldsymbol{U}_{\mathrm{n}}^{\mathrm{T}} \end{bmatrix} \end{aligned} \tag{4}$$

where $\boldsymbol{U}_{\mathrm{s}} \in \mathrm{R}^{N\times H}$, $\boldsymbol{U}_{\mathrm{n}} \in \mathrm{R}^{N\times(N-H)}$,$\boldsymbol{\Lambda}_{\mathrm{s}} \in \mathrm{R}^{H\times H}$, $\boldsymbol{\Lambda}_{\mathrm{n}} \in \sigma^2 \mathbf{I}_N$. The last equation due to $\boldsymbol{U}$ is orthogonal matrix. Combining Eq.(3) with Eq.(4) yields

$$\boldsymbol{S}\boldsymbol{I}_H\boldsymbol{S}^{\mathrm{T}} = \boldsymbol{U}_{\mathrm{s}}(\boldsymbol{\Lambda}_{\mathrm{s}} - \sigma^2 \boldsymbol{I}_H)\boldsymbol{U}_{\mathrm{s}}^{\mathrm{T}} \tag{5}$$

where range($\boldsymbol{U}_s$) is called signal subspace. It can be seen that range($\boldsymbol{S}$)=range($\boldsymbol{U}_{\mathrm{s}}$). User 2 generates and searches the scheduling tables of all users to find the set of users in "PT" state in current symbol interval denoted by E, and then generates the set of active user identification codes denoted by B_2 via executing xor operation between p_2 and the transmitter address code of each user in E.

The spectrum spreading codes transmitted by active users of user 2 is represented by set A_2. Since $A_2=A\cap B_2$ the purpose of active user identification is to identify the codes belonging to A from B_2. If A_2 is not empty the spectrum spreading codes in A_2 belong to range($\boldsymbol{U}_{\mathrm{s}}$). Therefore projecting codes in B_2 into $\boldsymbol{U}_{\mathrm{s}}$ as shown in Eq.(6) yields confidences set $D_2=\{ d_{i,2}, i\in E \}$.

$$d_{i,2} = \left\| \boldsymbol{U}_{\mathrm{s}}^{\mathrm{T}} s_{i,2} \right\|^2 = (\boldsymbol{U}_{\mathrm{s}}^{\mathrm{T}} s_{i,2})^{\mathrm{T}} (\boldsymbol{U}_{\mathrm{s}}^{\mathrm{T}} s_{i,2}), s_{i,2} \in B_2 \tag{6}$$

Assuming that the subspace estimation error can be ignored. If user i in E is the active user of user 2, then there must exist $s_{i,2}$ in B_2 that belongs to both B_2 and A, then its corresponding $d_{i,2}$ satisfies $d_{i,2}=N$. Conversely, if user i in E is not the active user of user 2, then the active user identification code generated by user i belongs to B_2 but not A, then the confidence of user i obeys $0 \le d_{i,2} < N$. In this ideal case, user 2 can easily identify active users based on the result of Eq. (6). However, in the real case, due to the effect of unavoidable subspace estimation error and channel noise, the confidence of user i also obeys $0 \le d_{i,2} < N$, even if user i is active user of user 2.

Therefore a judgment model shown in Eq.(7) is given to distinguish active users from inactive users, in which d_{th} denotes judgment threshold.

$$A_2 = \{ s_{i,2} \,|\, d_{i,2} \ge d_{\mathrm{th}}, s_{i,2} \in B_2, d_{i,2} \in D_2 \} \tag{7}$$

If all the confidences in D_2 are less than d_{th}, it means that user 2 doesn't have active user. Then user 2 discards the received packets; if there exist $d_{i,2}$ meets $d_{i,2} \ge d_{\mathrm{th}}$, it means that user i is the active user of user 2.

4 Simulation and analysis

In this paper one user is selected as the observation user, and it keeps in "L" state all the time during the simulation, while the states of the other users at each symbol interval are determined by their scheduling tables. The users in "PT" state transmit with equal probability, and randomly choose one user in "L" state as its destination. The experimental results is obtained over 1000 independent simulations under AWGN channel, Rician channel and Rayleigh channel with BPSK modulation format respectively. The parameters of the simulation is shown in Table 1, in which PL represents packet length, N represents spectrum spreading code length. T represents symbol interval.

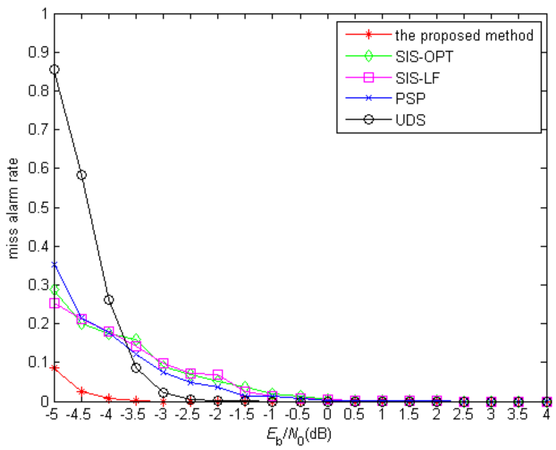
Table 1 Simulation parameters

Simulation parameters	Value

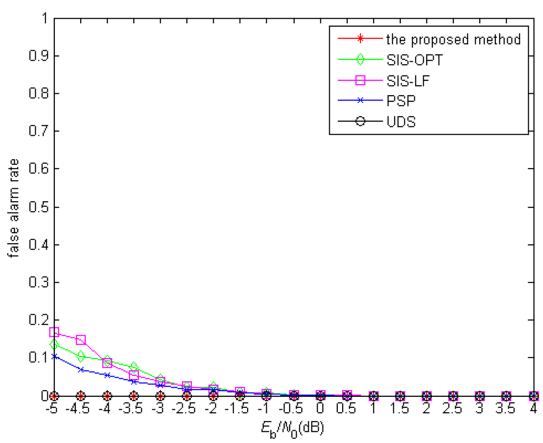
PL	10000bits
N	64bits
T	1×10^{-6}s

We compare miss alarm rate and false alarm rate between the proposed method and four reference methods advocated in literature [7] and [8]. Miss alarm rate indicates the probability that a user is active but judged as inactive user, while false alarm rate indicates the probability that a user is inactive but judged as active user. Three reference methods advocated in literature [7] are called SIS-OPT, SIS-LF, and PSP. One reference method advocated in literature [8] is called UDS.

4.1 AWGN channel



(a) Miss alarm rate VS E_b/N_0 under Q=20

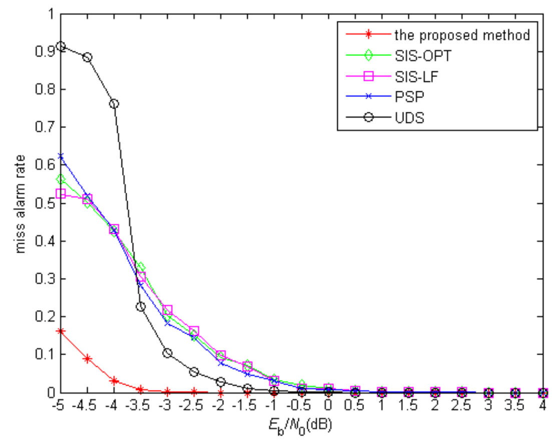


(b) False alarm rate VS E_b/N_0 under Q=20

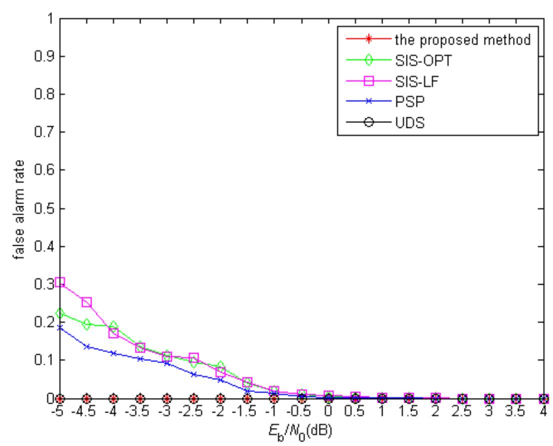
Fig.1 Performance of five methods under AWGN channel

Fig. 1 compares miss alarm rate and false alarm rate of the proposed method with that of the reference methods for different E_b/N_0 conditioning that Q=20 under AWGN channel. It can be seen from Fig.1(a) that the performance of UDS is poor in low E_b/N_0 due to the fact that the method is designed under ideal conditions. The proposed method achieves 1.16dB E_b/N_0 gains when miss alarm rate reaches 10^{-3} comparing with reference methods. It can be seen from Fig. 1(b) that the false alarm rate of the proposed method and UDS are both zero in all E_b/N_0 .

4.2 Rician channel



(a) Miss alarm rate VS E_b/N_0 under Q=20

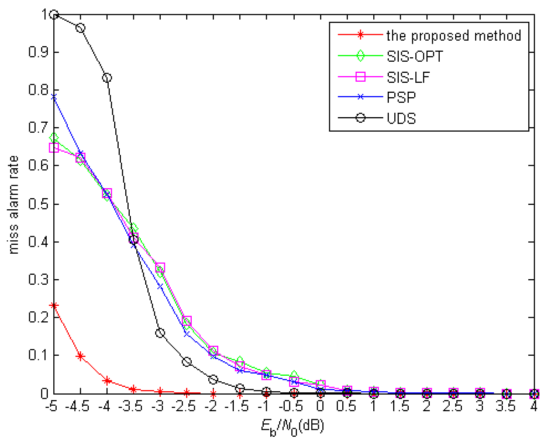


(b) False alarm rate VS E_b/N_0 under Q=20

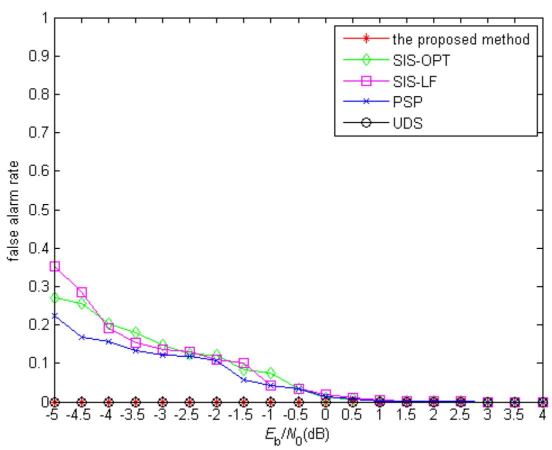
Fig.2. Performance of five methods under Rician channel

Fig. 2 compares miss alarm rate and false alarm rate of the proposed method with that of the reference methods for different E_b/N_0 conditioning that Q=20 under Rician channel. It can be seen from Fig. 2(b) that the false alarm rate of the proposed method and UDS remain zero in all E_b/N_0. It can be seen from Fig.2(a) that the performance of the five methods degrades comparing with Fig.1(a) due to the effect of multipath. The proposed method achieves 2.03dB E_b/N_0 gains when miss alarm rate reaches 10^{-3} comparing with reference methods. Therefore, the performance degradation of the proposed method is less than that of the reference methods.

4.3 Rayleigh channel



(a) Miss alarm rate VS E_b/N_0 under Q=20



(b) False alarm rate VS E_b/N_0 under Q=20

Fig.3. Performance of five methods under Rayleigh channel

Fig. 3 compares miss alarm rate and false alarm rate of the proposed method with that of the reference methods for different E_b/N_0 conditioning that Q=20 under Rayleigh channel. It can be seen from Fig. 3(b) that the false alarm rate of the proposed method and UDS remain zero in all E_b/N_0. It can be seen from Fig.3(a) that the performance of the five methods degrades comparing with Fig.2(a) due to lack of LoS signal. The proposed method achieves 2.26dB E_b/N_0 gains when miss alarm rate reaches 10^{-3} comparing with reference methods. Similarly, the performance degradation of the proposed method is less than that of the reference methods.

It can be seen from Fig.1 to Fig.3 that the performance of the proposed method outperforms the reference methods under all channel conditions especially in low E_b/N_0, and the performance gap between the proposed method and the reference methods is growing with the deterioration of channel conditions.

4 Conclusions

In space based constellation network, users are allowed to enter or leave the network arbitrarily. Hence active user identification has an important effect on the performance of space based constellation network. Existed active user identification methods have a high miss alarm rate in low SNR. Therefore a novel active user identification method is proposed in this paper. In order to resist multiple access interference and inter-symbol interference as well as reduce user energy consumption transmitter-receiver-based active user identification code is generated to spread spectrum. The active users are identified by comparing the confidences of all users which is obtained by processing the received signal via subspace-based method with judgment threshold.

We simulate the proposed method and the reference methods under AWGN channel, Rician channel and Rayleigh channel respectively. Experimental results show that the proposed method obtains at least 1.16dB E_b/N_0 gains comparing with reference methods when miss alarm rate reaches 10^{-3}. The performance of the proposed method is superior to the reference methods under all channel conditions mentioned above, and the worse the channel conditions, the greater the performance advantage.

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