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A Handover Decision Algorithm Based on Evolutionary Game Theory for Space-ground Integrated Network

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***Abstract*—When handovers occur to user in space-ground integrated network, handover decisions should be made to select the optimal access point. However, existing decision indexes are not suitable to handover scenarios in space-ground integrated network and overlooks the overall performance of network. To address these issues, a handover decision algorithm based on evolutionary game theory was proposed. Firstly, handover indexes were selected from aspects of link quality, network quality, load balance and user demand, and weight matrix was established. Secondly, membership function was introduced to normalize the decision indexes, and user utility function and cost function of access points were designed according to the impact of indexes on handover performance and cost. Finally, evolutionary game theory is introduced to construct a handover decision model, whose stability strategy indicates the optimal access point. Experiment results show that the algorithm can meet the seamless handover requirements, and possesses high accuracy and validity.**

Keywords—handover decision; evoluitonary game theory; stability strategy; space-ground integrated network

I. INTRODUCTION

End-users in space-ground integrated network would face frequent handover duo to high-speed movement of satellites and intermittent connected links. When handover occurs to an end user terminal, it's usually covered by several access points simultaneously. As the node performance, network quality of service and security level of these access points are different and the performance requirements of end-users differ from each other, making reasonable handover decision is of great importance to select the right access point. Otherwise, unreasonable selection of access point would lead to poor user experience.

Existing researches [1-3] on handover decision have made great progress. Liu [4] proposes a handoff decision algorithm based on analytic hierarchy process for WLAN/Cellular network. Fan [5] a vertical handoff method with Bayesian decision was proposed for heterogeneous wireless network environment of IoV including WAVE, WiMAX and 3G cellular. Dong [3] proposes a formal model of power control and vertical handover of radio resource management based on evolutionary game theory. However, they cannot be entirely applicable to the space-ground integrated network with intermittently connected links and dynamic topology.

To address these issues, a handover decision algorithm based on evolutionary game theory for the space-ground integrated network. First, handover decision indexes tree including network topology, load balance and users' demand are built to optimize the overall performance of network. Then membership function is introduced to normalize the decision indexes, and user utility function and cost function of access points are designed to describe the cost and utility of selecting an access point. Finally, a handover decision model is constructed based on evolutionary game theory. Additionally, experiments results prove the efficiency and accuracy.

II. HANDOVER DECISION MODEL

A. Decision Indexes Tree

Aiming at satisfying users' requirements and ensuring overall performance, a decision indexes tree is built from the user-centered and network-centered aspects. Decision indexes of each aspect are shown in figure Ⅰ.

1) Received signal strength indication (RSSI)

RSSI reflects quality of current channel and is the primary condition of handover decision. When and only when RSSI is higher than the threshold, the link can be established. The RSSI formula is

$$rssi = \frac{P_T \cdot G_T \cdot A \cdot \eta}{4\pi d^2} \tag{1}$$

Where, P_T is the transmit power of antenna, G_T is the transmit gain of antenna, $A\eta$ is the effective area of receiving antenna, d is transmission distance for free space.

2) Elevation

Elevation refers to the angle from the horizon to the satellite with the user terminal as the vertex in the plane composed of user terminal, satellite point and base station. The expression of elevation is

$$\alpha = \arccos\left(\frac{(\mathbf{r}_2-\mathbf{r}_1)\cdot\mathbf{r}_2}{|\mathbf{r}_2-\mathbf{r}_1|\cdot\mathbf{r}_2}\right) - 90^\circ \tag{2}$$

Where $\boldsymbol{r}_1, \boldsymbol{r}_2$ are respectively the location of base station and end-user.

3) Coverage time

Coverage time refers to the length of time that the current base station provides services to users. The longer the base station coverage time, the lower the handover arrival rate of user terminals and the higher the business continuity. The expression of coverage time is

$$P_c = 1 - (1 - P_e)^m \tag{3}$$

4) Maximum transmission rate

Transmission rate directly affects the quality of services. According to Shannon's theorem, the maximum transmission rate of the channel is as follows.

$$C = B \cdot In\left(1 + \frac{E_b}{N_0}\right) \tag{4}$$

Where B is bandwidth and $\frac{E_b}{N_0}$ is signal-to-noise ratio.

5) Bit error rate (BER)

The space environment has a great influence on the BER of satellite links. When the BER of the network is higher than the maximum BER, it is difficult to meet the QoS requirements of end users, which will lead to the link will not be established normally. Bit error rate of inter-satellite link or satellite-ground link is usually calculated based on antenna parameters.

$$\mathrm{P_c} = 1 - (1 - \mathrm{P_e})^{\mathrm{m}} \tag{5}$$

$$P_e = \frac{1}{2}\left(1 - erf\left(\sqrt{\frac{E_b(1-\rho)}{2N_0}}\right)\right), erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}\, d\, t \tag{6}$$

Where erf is error function, $\frac{E_b}{N_0}$ is signal-to-noise ratio and ρ waveform correlation function.

6) User preference

User preference refers to the type of service most suitable for a network transmission, which is related to the characteristics of the network itself and the type of service. User preference is defined as following equation.

$$W = \alpha(w_1 \quad w_2 \quad \cdots \quad w_n)^T + \beta(up_1 \quad up_2 \quad \cdots \quad up_n)^T$$

Where, $(up_1 \quad up_2 \quad \cdots \quad up_n)^T$ is user preferences vector, α, β are respectively the weights of quality of service and user preferences.

7) Degree of invulnerability

If a large number of users access some base stations centrally, once attacking these base stations, the network will be paralyzed. Therefore, topology invulnerability should be considered in access decision. The invulnerability is usually defined as the average distance of the network and is defined as follows.

$$NI = \frac{\sum_{1 \le i \le j \le n} L(i,j)}{\frac{n(n-1)}{2}} \tag{7}$$

Where n is nodes number and $L(i,j)$ is distance between node i and node j.

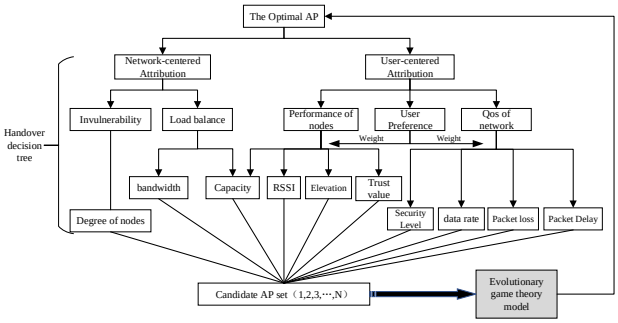

FIGURE I. HANDOVER DECISION MODEL AND DECISION INDEX TREE

B. User Utility Function and Cost Function

The access of end-users will inevitably affect the performance parameters of the network where the access point locates, and different networks have different tolerance to this effect, so a cost function should be introduced to characterize the cost of user access. Because the impact of access cost on network performance is usually manifested in the changes of multiple factors, the cost function should comprehensively evaluate these factors and present them in the form of function values for base station selection.

The decision indexes chosen for the cost function is set to be indexes that affect the load balance of access points. According to the decision indexes tree, affection of elevation agl, Received Signal Strength Indication $rssi$, trust value td and user preference is very small. Thus, the decision indexes set is defined as following equation

$$PRC = \{pdly, bd, drate, load, resrate\}.$$

Definition 1 Cost function of access point ap_i is defined as following equation.

$$\mathrm{P^i} = \sum_{\mathrm{j=1}}^{\mathrm{m}} \mathrm{w_j} \times \mathrm{pr}\left(\mathrm{f(c_j)}\right) \tag{8}$$

Where $m = 5$ is the scale of indexes of cost function, w_j is the weight of the j-th index, $f\left(c_j\right)$ is the normalized function acts on the j-th index, and $pr\left(f\left(c_j\right)\right)$ is the cost of the j-th index. The weight of each index can be calculated using analytic hierarchy process (AHP).

Definition 2 User utility function E of access point ap_i is defined as following equation

$$E = U_i - P^i \tag{9}$$

$$U = \frac{1}{1+exp\left(-a\left(\sum_i w_i f(x_i) - b\right)\right)} \tag{10}$$

C. Evolutionary Game Theory Model for Handover Decision

To select an optimal access point for handover, an evolutionary game theory model is constructed. In evolutionary game, the node participating in the game does not strategically

choose its own target access point or trust the identity of the target node, but formulates a given strategy, and then decides whether the strategy can withstand the invasion of other mutation strategies. If other mutation strategies cannot invade the current system, it shows that the gains from using the given strategy are higher than the mutation strategy. Revenue, then the strategy is a stable strategy.

Definition 3 Evolutionary game theory model (EGTM) for handover decision is defined as a tuple as following.

$$Egathdm = \{V, S, P, w, \Delta^{ESS}, \Delta^{RD}, E\} \tag{11}$$

Where V is available access points set, S is selection strategies, $P = \{P^1, P^2, \cdots, P^n\}$ are cost function set and P^i is the cost function of the *i*-th access point, W is weight of decision indexes, Δ^{ESS} is the stability strategy of evolutionary game model, Δ^{RD} is duplicator dynamics and E is net profit.

Suppose the speed of strategies switch is δ, then duplicate dynamic dynamics equation is

$$\Theta_k = \delta x_k \left(E_k - \overline{E}\right) \tag{12}$$

Where $\overline{E} = \sum_{i=1}^{M} x_i E_i$ is the average user utility of all user nodes. As is shown in equation 17, when user utility of an access point is larger than the average value, the probability that this access point is selected increases which leads to the decrease of user experience. This process will finally result to the value of Θ_k to be 0.

Theorem 1 There is a unique evolutionary stability strategy ESS for the handover decision model.

Proof: During the handover decision, the best access point is the one with maximum user utility. And the maximum user utility can be calculated by finding partial derivatives of Θ_k. Set partial derivatives of Θ_k to be 0. There is

$$\frac{\partial \Theta_k}{\partial x_k} = \frac{\delta x_k\left((1-x_k)E_k - \sum_{i \neq k} x_i E_i\right)}{\partial x_k} = 0 \tag{13}$$

Then, we can get the solution

$$x_k^* = 1 - \frac{\overline{E}}{E_k} \tag{14}$$

It can be inferred that x_k^* is less than 0 when $E_k \leq \overline{E}$. Thus, the probability that the *k*-th AP is selected is 0. x_k^* is greater than 0 when $E_k \geq \overline{E}$, where x_k^* is the only stability strategy. And the larger value of E_k is, the greater the probability of being selected.

III. EXPERIMENTS

In this section, experiments are conducted from the aspects of stability strategy, ping-pang rate and load balance with OPnet.

A. Settings

TABLE I. NETWORK PARAMETER SETTINGS FOR HANDOVER DECISION

Parameters	Values
Number of born nodes/access nodes/user nodes	10/50/200
Height(km)	40/30
Coverage radius (km)	40
Speed of user nodes V (km/s)	0.3
Maximum service time T_s(min)	3.67
Handover request arrival rate（10^{-4}calls/sec）	1.2
Request duration (s)	150
Simulation duration (h)	8

The simulation parameters of simulated network parameters are listed in Table I. During the simulation, access network is constructed by access nodes and end-users select its access point for handover based on the proposed algorithm. Suppose that end-users move straightly at a presupposed uniform speed and height. Set TOPSIS [7] and FuzzTOPSIS [8]be the baselines.

TABLE II. PERFORMANCE OF AP SET AT TIME T

Items	AP1	AP2	AP3	AP4	AP5	AP6	AP7
Security Level	7	6	4	5	4	3	5
Trust Value	0.9	0.6	0.3	0.5	0.7	0.7	0.5
Capacity	100	100	100	80	90	90	80
Current Load	48	32	36	34	40	50	30
Elevation	30.5	24.2	18.3	21.7	43.2	26.4	20.9
Packet Delay	0.30	0.29	0.26	0.33	0.39	0.53	0.34
Bandwith	0.49	0.33	0.57	0.24	0.34	0.41	0.38
Packet loss	0.41	0.27	0.56	0.44	0.39	0.31	0.36

Randomly initialize the security level, reliability, access capacity and user preferences of backbone nodes/access points. Modify node models in OPNet to add some process models such as elevation measurement, signal strength detection, network state acquisition, and obtain the indexes values of the candidate access points. At time t, the value of decision index parameters of an optional access point in a certain area is shown in Table II.

B. Perofrmance Analysis

1) Stability strategy

Set evolution speed rate $\delta = 3$. Figure Ⅱ shows the net utility evolutionary curve of the 7 access points. From figure 2, net utility of AP1 is largest and that of AP7 is smallest. As the evolution goes, net utility of all Aps approaches 0.6, which indicates the stable strategy.

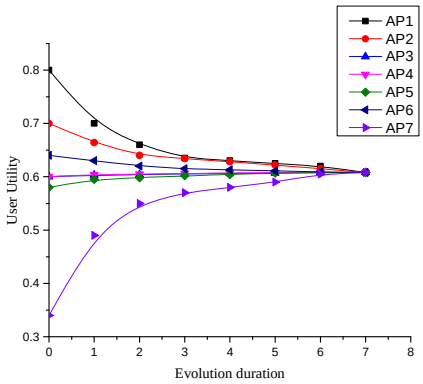

FIGURE II. NET UTILITY EVOLUTIONARY CURVE

2) Ping-pang rate

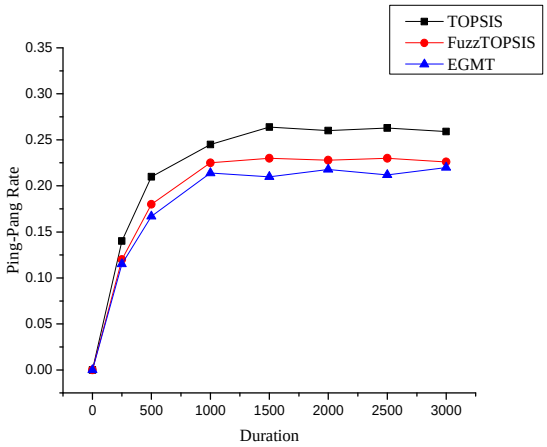

FIGURE III. PING-PONG RATE UNDER DIFFERENT HANDOVER DECISION ALGORITHM

Figure Ⅲ shows the ping-pang rate of handover under different decision algorithm. It can be found that there is little difference in ping-pang rate of these algorithms and the ping-pang rate of TOPSIS is largest. The reason is that the TOPSIS considers only quality of downlink and downlink, but not the overall service quality of users. Ping-pang rates of FuzzTOPSIS and EGMT are relatively close and the former is a litter larger than the EGMT. As TOPSIS and FuzzTOPSIS do not take load balance into account, and when the load increases, performance of access point decrease leading to higher ping-pang rate.

3) Load balance

Figure Ⅳ shows the variance comparison of nodes' degree under different algorithm. We can see that variance of nodes' degree under EGMT is smallest and that of TOPSIS is largest. It can be inferred that EGMT takes the load into account to achieve better load balance. With the evolution goes, the load is similar among all access points, degree of each access point is similar.

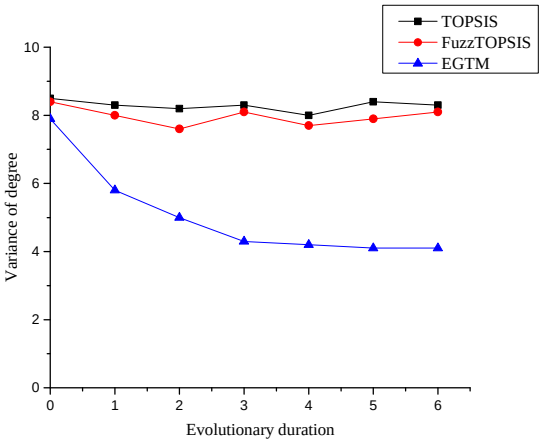

FIGURE IV. VARIANCE COMPARISON OF NODES' DEGREE

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