I. Evolutionary Analysis of Payoffs for Data, Validation, and Proxy Nodes Under Different Strategies

Referencing the payoff matrix in Table I, the payoff of data nodes for choosing honest behavior U_{11}, the payoff for choosing malicious behavior U_{12}, and the average expected payoff for data nodes choosing between the two strategies $\overline{U}_1$ are calculated as follows:

$$\begin{aligned} U_{11} &= yz\left(\phi R_D - C_D\right) + (1-y)z\left(\phi R_D - C_D\right) + y(1- \\ &\quad z)\left(\phi RD - CD + r\right) + (1-y)(1-z)\left(\phi R_D - C_D\right) \\ &= \phi R_D - C_D + yr - yzr, \end{aligned} \tag{1}$$

$$\begin{aligned} U_{12} &= yz\left(-C_D - P_D\right) + (1-y)z\left(-C_D - C_C - P_D\right) + \\ &\quad y(1-z)\left(\phi R_D - C_D\right) + (1-y)(1-z)(R_{MD} - \\ &\quad C_D - C_C) \\ &= y\left(C_C - R_{MD} + \phi R_D + zR_{MD} - z\phi R_D\right) + R_{MD} - \\ &\quad C_D - C_C - zP_D - zR_{MD}, \end{aligned} \tag{2}$$

and

$$\overline{U}_1 = xU_{11} + (1-x)U_{12}, \tag{3}$$

The payoff of validator nodes for choosing honest behavior U_{21}, the payoff for choosing malicious behavior U_{22}, and the average expected payoff for validator nodes choosing between the two strategies $\overline{U}_2$ are calculated as follows:

$$\begin{aligned} U_{21} &= xz\left(R_V - C_V\right) + (1-x)z\left(R_V - C_V\right) + \\ &\quad x(1-z)\left(R_V - C_V + r\right) + (1-x)(1-z)\left(R_V - C_V\right) \\ &= R_V - C_V + xr - xzr, \end{aligned} \tag{4}$$

$$\begin{aligned} U_{22} &= xz\left(-C_V - P_V\right) + (1-x)z\left(-C_V - P_V\right) + \\ &\quad x(1-z)\left(R_V - C_V\right) + (1-x)(1-z)\left(R_{MV} - C_V\right) \\ &= \left(R_V - R_{MV} + zR_{MV} - zR_V\right)x + R_{MV} - C_V - \\ &\quad zP_V - zR_{MV}, \end{aligned} \tag{5}$$

and

$$\overline{U}_2 = yU_{21} + (1-y)U_{22}. \tag{6}$$

Similarly, the payoff of proxy nodes for choosing honest behavior U_{31}, the payoff for choosing malicious behavior U_{32}, and the average expected payoff for proxy nodes choosing between the two strategies $\overline{U}_3$ are calculated as follows:

$$\begin{aligned} U_{31} &= xy\left(R_B - C_B - C_S\right) + (1-x)y(R_B - \\ &\quad C_B - C_S + P_D) + x(1-y)(R_B - C_B - C_S + \\ &\quad P_V) + (1-x)(1-y)\left(R_B - C_B - C_S + P_D + P_V\right) \\ &= R_B - C_B - C_S + (1-y)P_V + (1-x)P_D, \end{aligned} \tag{7}$$

$$\begin{aligned} U_{32} &= xy\left(R_B - C_B + r\right) + (1-x)y\left(R_B - C_B - \theta P_S\right) \\ &\quad + x(1-y)\left(R_B - C_B - \theta P_S\right) + (1-x)(1-y)(R_B - \\ &\quad C_B - \theta P_S) \\ &= R_B - C_B + (xy-1)\theta P_S + xyr, \end{aligned} \tag{8}$$

and

$$\overline{U}_3 = zU_{31} + \ (1-z)U_{32}. \tag{9}$$

Based on replicator dynamics theory [1], we derive the evolutionary dynamics equations for the strategy probabilities of data, validator, and proxy nodes. The growth rates of probabilities x, y, and z for honest strategies among data, validator, and proxy nodes are proportional to the differences between their respective payoffs U_{11}, U_{21}, U_{31} and average payoffs $\overline{U}_1$, $\overline{U}_2$, $\overline{U}_3$. Then the evolutionary dynamics of strategy probabilities for data, validator, and proxy nodes are given by $F_D(x)$, $F_V(y)$, and $F_P(z)$, respectively, expressed as.

$$\begin{aligned} F_D(x) &= \frac{dx}{dt} = x\left(U_{11} - \overline{U}_1\right) \\ &= -x(x-1)[C_C - R_{MD} - yC_C + \phi R_D + zP_D \\ &\quad + yR_{MD} + zR_{MD} + yr - y\phi R_D - yzR_{MD} \\ &\quad - ryz + yz\phi R_D] \end{aligned} \tag{10}$$

$$\begin{aligned} F_V(y) &= \frac{dy}{dt} = y\left(U_{21} - \overline{U}_2\right) \\ &= -y(y-1)[R_V - R_{MV} + xR_{MV} + zP_V - xR_V \\ &\quad + zR_{MV} + xr - xzR_{MV} + xzR_V - xzr], \end{aligned} \tag{11}$$

and

$$\begin{aligned} F_P(z) &= \frac{dz}{dt} = z\left(U_{31} - \overline{U}_3\right) \\ &= z(z-1)C_S - P_D - P_V - \theta P_S + xP_D + yP_V \\ &\quad + xyr + xy\theta P_S. \end{aligned} \tag{12}$$

TABLE I: Payoff matrix

				VN	
				H	M
PN	S	DN	H	$(\phi R_D - C_D, R_V - C_V, R_B - C_B - C_S)$	$(\phi R_D - C_D, -C_V - P_V, R_B - C_B - C_S + P_V)$
			M	$(-C_D - P_D, R_V - C_V, R_B - C_B - C_S + P_D)$	$(-C_D - C_C - P_D, -C_V - P_V, R_B - C_B - C_S + P_D + P_V)$
	NS	DN	H	$(\phi R_D - C_D + r, R_V - C_V + r, R_B - C_B + r)$	$(\phi R_D - C_D, R_V - C_V, R_B - C_B - \theta P_S)$
			M	$(\phi R_D - C_D, R_V - C_V, R_B - C_B - \theta P_S)$	$(R_{MD} - C_D - C_C, R_{MV} - C_V, R_B - C_B - \theta P_S)$

REFERENCES

[1] T. Mai, H. Yao, N. Zhang, L. Xu, M. Guizani, and S. Guo, "Cloud mining pool aided blockchain-enabled Internet of Things: An evolutionary game approach," *IEEE Trans. Cloud Comput.*, vol. 11, no. 1, pp. 692–703, Jan.-Mar. 2023.