Appendix A
Proof of Lemma 1

Lemma 1. *Given any feasible task replication and power allocation, the Lyapunov drift-plus-penalty function B in our formulation is upper bounded by the following expression.*

$$B \geq \frac{1}{2}E\left[(Q(t))^2+\omega^2\right] + \frac{1}{2}\sum_{i=1}^{I}E\left[\left(\frac{1}{T}\sum_{t=0}^{T-1}D_{i,b}(t)\right)^2+\epsilon^2\right],$$

where ω is the restricted queue length in the cloud, and $R_{i,b}(t)$ is denoted as the total amount of computing from TaV i in the time slot t, ϵ is the average delay constraint.

Proof. By squaring both sides of the equation , we can get the expression below.

$$\begin{aligned}H(t+1)^2 &= \left(\max\left\{H(t)+Q(t)-\omega,0\right\}\right)^2\\ &\leq H(t)^2+\omega^2+Q(t)^2+2H(t)Q(t)\\ &-2\omega Q(t)-2\omega H(t).\end{aligned}$$

The following inequality can be obtained as follows.

$$\begin{aligned}&\frac{1}{2}[H(t+1)^2-H(t)^2] \leq \frac{1}{2}\left(\omega^2+Q(t)^2\right.\\ &\left.+2Q(t)H(t)-2\omega Q(t)-2\omega H(t)\right)\\ &\leq \frac{1}{2}\left[Q(t)^2+\omega^2+2H(t)\left(Q(t)-\omega\right)\right].\end{aligned}$$

Similarly, we can obtain the following expression.

$$\begin{aligned}&\frac{1}{2}\sum_{i=1}^{I}[G_i(t+1)^2-G_i(t)^2] \leq \frac{1}{2}\sum_{i=1}^{I}\left[\left(\sum_{t=0}^{T-1}D_{i,b}(t)\right)^2\right.\\ &\left.+\epsilon^2+2G_i(t)\left(\sum_{t=0}^{T-1}D_{i,b}(t)-\epsilon\right)\right].\end{aligned}$$

According to the definition of Lyapunov drift function, we can get the expression below.

$$L(\Theta(t)) = \frac{1}{2}\left((H(t))^2+\sum_{i=1}^{I}(G_i(t))^2\right),$$

$$\triangle L(t) = E[L(\Theta(t+1))-L(\Theta(t))].$$

Then, we can get a bound on $\triangle L(t)$.

$$\begin{aligned}\triangle L(t) &\leq B+\left[H(t)\left(Q(t)-\omega\right)\right.\\ &\left.+\sum_{i=1}^{I}G_i(t)\left(\sum_{t=0}^{T-1}D_{i,b}(t)-\epsilon\right)\right],\end{aligned}$$

where B is upper bounded by the expression as below.

$$B \geq \frac{1}{2}E\left[(Q(t))^2+\omega^2\right] + \frac{1}{2}\sum_{i=1}^{I}E\left[\left(\frac{1}{T}\sum_{t=0}^{T-1}D_{i,b}(t)\right)^2+\epsilon^2\right].$$

□

Appendix B
Proof of Lemma 2

Lemma 2. *The BER $\Omega_{i,b}(t)$ between TaV i and the edge cloud and the BER $\Omega_{i,j}(t)$ between TaV i and SeV j under Rayleigh fading conditions have the approximation as below.*

$$\Omega_{i,b}(t) \approx \frac{(e^{R_{i,b}(t)}-1)\left(\sum_{k=i+1}^{I}\left|h_{k,b}(t)\right|^2\alpha_i^n(t)p_{k,b}(t)+\sigma^2\right)}{p_{i,b}(t)\left|h_{i,b}(t)\right|^2},$$

$$\Omega_{i,j}(t) \approx \frac{(e^{\frac{K_{i,j}}{L_{i,j}}}-1)\sigma^2}{p_{i,j}(t)\left|h_{i,j}(t)\right|^2}.$$

Proof. According to Taylor's Expanded Form, we can get the approximations of BER as below.

$$\begin{aligned}\Omega_{i,b}(t) \approx& 1-k_1\gamma_{i,b}(t)\left(1+\frac{k_2}{\gamma_{i,b}(t)}+\frac{k_2^2}{2{\gamma_{i,b}}^2(t)}\right.\\ &\left.-1-\frac{k_3}{\gamma_{i,b}(t)}-\frac{k_3^2}{2{\gamma_{i,b}}^2(t)}\right),\end{aligned}$$

where $k_1=\sqrt{\frac{L_{i,b}}{2\pi(e^{2\frac{K_{i,b}}{L_{i,b}}}-1)}}$, $k_2=1-e^{\frac{K_{i,b}}{L_{i,b}}}+\sqrt{\frac{\pi(e^{2\frac{K_{i,b}}{L_{i,b}}}-1)}{2L_{i,b}}}$, and $k_3=1-e^{\frac{K_{i,b}}{L_{i,b}}}-\sqrt{\frac{\pi(e^{2\frac{K_{i,b}}{L_{i,b}}}-1)}{2L_{i,b}}}$.

$$\begin{aligned}\Omega_{i,j}(t) \approx& 1-g_1\gamma_{i,j}(t)\left(1+\frac{g_2}{\gamma_{i,j}(t)}+\frac{g_2^2}{2\gamma_{i,j}^2(t)}\right.\\ &\left.-1-\frac{g_3}{\gamma_{i,j}(t)}-\frac{g_3^2}{2{\gamma_{i,j}}^2(t)}\right),\end{aligned}$$

where $g_1=\sqrt{\frac{L_{i,j}}{2\pi(e^{2\frac{K_{i,j}}{L_{i,j}}}-1)}}$, $g_2=1-e^{\frac{K_{i,j}}{L_{i,j}}}+\sqrt{\frac{\pi(e^{2\frac{K_{i,j}}{L_{i,j}}}-1)}{2L_{i,j}}}$, and $g_3=1-e^{\frac{K_{i,j}}{L_{i,j}}}-\sqrt{\frac{\pi(e^{2\frac{K_{i,j}}{L_{i,j}}}-1)}{2L_{i,j}}}$.

After simplification, we can obtain the below expressions.

$$\Omega_{i,b}(t) \approx \frac{(e^{\frac{K_{i,b}}{L_{i,b}}}-1)\left(\sum_{k=i+1}^{I}\left|h_{k,b}(t)\right|^2p_{k,b}(t)+\sigma^2\right)}{p_{i,b}(t)\left|h_{i,b}(t)\right|^2},$$

$$\Omega_{i,j}(t) \approx \frac{(e^{\frac{K_{i,j}}{L_{i,j}}}-1)\sigma^2}{p_{i,j}(t)\left|h_{i,j}(t)\right|^2}.$$

□

Appendix C
Proof of Lemma 3

Lemma 3. *The expected service reliability incurred by PA-TRLF could achieve the effect that has a gap with the maximal service reliability, which can be described below.*

$$\lim_{T\to\infty}\frac{1}{T}\sum_{t=0}^{T-1}E\{\Upsilon(t)|\Theta(t)\} \leq \Upsilon^{\sup}(t)-\frac{B}{V},$$

where $\Upsilon^{\sup}(t)$ is the supremum of the average service reliability achieved by any joint strategy under the required constraints, and B is mentioned in ***Lemma 1****.*

Proof. From **Lemma 2**, we can get the below expression.

$$\triangle L(t) - VE\{\Upsilon(t)|\Theta(t)\} \leq B + H(t)E\{Q(t)-\omega|\Theta(t)\} + \sum_{i}^{I} G_i(t)E\{\frac{1}{T}\sum_{t=0}^{T-1} D_{i,b}(t) - \epsilon|\Theta(t)\} - VE\{\Upsilon(t)|\Theta(t)\}.$$

B is the upper bound, which is mentioned in **Lemma 1**. From **Section 3.1.4** in the study [16], we have the following inequality.

$$B - V\Upsilon^{\sup}(t) \leq \triangle L(t) - VE\{\Upsilon(t)|\Theta(t)\}.$$

By adding $t = 0, 1, \ldots, T-1$ cumulatively, we get:

$$TB - TV\Upsilon^{\sup}(t) \leq E\left\{L(\Theta(t)) - L(\Theta(0))\right\} - V\sum_{t=0}^{T-1} E\left\{\Upsilon(t)|\Theta(t)\right\}.$$

Since $L(\Theta(t)) \geq 0, L(\Theta(0)) = 0$, both sides divide by the same $-TV$, when $t \to +\infty$, we can obtain that:

$$\limsup_{t\to+\infty} \frac{1}{t}\sum_{t=0}^{T-1} E\left\{\Upsilon(t)\right\} \leq \Upsilon^{\sup}(t) - \frac{B}{V}.$$

With Jensen's inequality, we can get:

$$\lim_{T\to\infty} \frac{1}{T}\sum_{t=0}^{T-1} E\left(\Upsilon(t)\right) \leq \Upsilon^{\sup}(t) - \frac{B}{V}.$$

□

Appendix D
Proof of Lemma 4

Lemma 4. *The virtual task queue in the edge cloud and the virtual delay queue for all TaVs in NOMA-enabled VEC are stable, which can be presented as follows.*

$$\lim_{T\to\infty} \frac{1}{T}\sum_{t=0}^{T-1} \left(E\{H(t)\} + \sum_{i=1}^{I} E\{G_i(t)\}\right) \leq \frac{V(\hat{\Upsilon}(t) - \check{\Upsilon}(t)) - B}{\varsigma},$$

where $\hat{\Upsilon}(t)$ and $\check{\Upsilon}(t)$ are defined as the maximum and minimum service reliability among all strategies. B is mentioned in ***Lemma 1****.*

Proof. We now prove that $Q(t)$ and $G_i(t)$ are mean rate stable under Algorithm 3.

Denote $\Phi(t) = TV\{\hat{\Upsilon}(t)\} - V\sum_{t=0}^{T-1} E\left\{\Upsilon(\bar{t})|\Theta(t)\right\} - TB + E\left\{L(\Theta(0))\right\}$.

Based on **Lemma 3**, we can get $E\{L(\Theta(t))\} \leq \Phi(t)$, i.e., $E\{H(t)^2\} \leq 2\Phi(t)$ and $E\{\sum_{i=1}^{I} G_i(t)^2\} \leq 2\Phi(t)$. Thus, we have the following inequality.

$$0 \leq E\{H(t)\} \leq \sqrt{2\Phi(t)}.$$
$$0 \leq \sum_{i=1}^{I} E\{G_i(t)\} \leq \sqrt{2\Phi(t)}.$$

Since $\lim_{T\to\infty} \frac{\sqrt{2\Phi(t)}}{T} = 0$, we can also acknowledge that

$$\lim_{T\to\infty} \frac{E\{H(t)\}}{T} = 0.$$
$$\lim_{T\to\infty} \sum_{i=1}^{I} \frac{E\{G_i(t)\}}{T} = 0.$$

To find the upper bound of the average sum queue length of $E\{H(t)\}$ and $\sum_{i=1}^{I} E\{G_i(t)\}$, we can obtain the below expression in the proof of **Lemma 3**,

$$L(\Theta(t+1)) - L(\Theta(t)) - VE\{\Upsilon(t)|\Theta(t)\} \geq \left[\sum_{i=1}^{I} G_i(t)\left(\frac{1}{T}\sum_{t=0}^{T-1} D_{i,b}(t) - \epsilon\right) + H(t)\left(Q(t) - \omega\right)\right] + B - V\Upsilon^{\sup}(t),$$

where $\Upsilon^{\sup}(t)$ is the supremum of the average service reliability achieved by any joint strategy under the required constraints.

Then, summing over $t \in \{0, 1, 2, \cdots, T-1\}$, we can obtain the expression below.

$$L(\Theta(T)) - L(\Theta(0)) - \sum_{t=0}^{T-1} VE\{\Upsilon(t)|\Theta(t)\} \geq TB - TV\Upsilon^{\sup}(t) + \varsigma\left(E\{H(t)\} + \sum_{i=1}^{I} E\{G_i(t)\}\right),$$

where $\varsigma > 0$, and after dividing T and ς by both sides of the above inequality, we can finally get.

$$\frac{1}{T}\left(E\{H(t)\} + \sum_{i=1}^{I} E\{G_i(t)\}\right) \leq \frac{E(L(T))}{\varsigma T} - \frac{E(L(0))}{\varsigma T} - \frac{B - V\Upsilon^{\sup}(t) + \frac{1}{T}\sum_{t=0}^{T-1} VE\{\Upsilon(t)|\Theta(t)\}}{\varsigma},$$

$$\Upsilon^{\sup}(t) - \frac{1}{T}\sum_{t=0}^{T-1} E\{\Upsilon(t)|\Theta(t)\} \leq \hat{\Upsilon}(t) - \check{\Upsilon}(t).$$

From the predefined value $L(0)$, we can get the conclusion.

$$\lim_{T\to\infty} \frac{1}{T}\sum_{t=0}^{T-1} \left(E\{H(t)\} + \sum_{i=1}^{I} E\{G_i(t)\}\right) \leq \frac{V(\hat{\Upsilon}(t) - \check{\Upsilon}(t)) - B}{\varsigma}.$$

□