Supplementary Information for " Enabling Edge Caching Through Full-duplex Non-orthogonal Multiple Access "

Case I: The channel condition between edge node E_0 and $UE_{d,m}$ is better than that between E_0 and $UE_{r,m}$, i.e., $\mathbb{E}\{|h_{0d,m}|^2\}{>}\mathbb{E}\{|h_{0r,m}|^2\}$.

Case II: The channel condition between edge node E_0 and $UE_{r,m}$ is better than that between E_0 and $UE_{d,m}$, i.e., $\mathbb{E}\{|h_{0r,m}|^2\}{>}\mathbb{E}\{|h_{0d,m}|^2\}$.

According to the NOMA protocol, the user with better channel condition will be allocated with lower transmit power of E_0, and decodes the message intended for another user while taking its desired message as interference (successive interference cancellation process). Then, it removes this message from superposed signal and decodes its desired message without any interference. In contrast, the user with worse channel condition will be allocated with larger transmit power of E_0, and decodes its desired message from the superposed signal directly.

The successful transmission probability and successful SIC probability are derived as follow.

A. *Successful Transmission Probability for Case I*

The large scale fading with $r_{(\cdot)}^{-\alpha}$ and Rayleigh fading channel with $g_{(\cdot)}{\sim}$Exp(1) are assumed, where the channel power gain satisfies $|h_{(\cdot)}|^2{=}r_{(\cdot)}^{-\alpha}g_{(\cdot)}$. Especially, $|h_{SI}|^2{=}g_{SI}$, where g_{SI} ~Exp($\frac{1}{\sigma_{SI}^2}$) is predefined. In Case I, after performing successive interference cancellation (SIC), the $UE_{d,m}$ decodes its preferred message without the interference. Therefore, the successful transmission probability for $UE_{d,m}$, i.e., $T_{d,m,1}$, can be formulated as follows,

$$\begin{aligned}
&T_{d,m,1}{=}\mathbb{P}\left(\frac{|h_{0d,m}|^2P_{0,m}\gamma_{d,m}}{N_{d,m}w_m}>\delta_m^{th}\right),\\
&=\mathbb{P}\left(\frac{g_{0d,m}r_{0d,m}^{-\alpha}P_{0,m}\gamma_{d,m}}{N_{d,m}w_m}>\delta_m^{th}\right),\\
&=\exp\left(-\frac{\delta_m^{th}N_{d,m}w_m}{r_{0d}^{-\alpha}P_{0,m}\gamma_{d,m}}\right),
\end{aligned} \tag{1}$$

As for the $UE_{r,m}$, it decodes desired message while taking the message intended for $UE_{d,m}$ as interference. Thus, the successful transmission probability for $UE_{r,m}$ via a relay link, i.e., $T_{r,m,1}$, is obtained as,

$$\begin{aligned}
T_{r,m,1} &= \mathbb{P}\left[\min\left(\xi_{r,m}^{0}, \xi_{r,m}\right) > \delta_{\mathrm{m}}^{\mathrm{th}}\right], \\
&= \mathbb{P}\left(\frac{g_{k0} r_{k0}^{-\alpha} P_{k,m}}{g_{SI} P_0 + N_0 w_m} > \delta_{\mathrm{m}}^{\mathrm{th}}\right) \mathbb{P}\left(\frac{g_{0r,m} r_{0r}^{-\alpha} P_{0,m} \gamma_{r,m} + g_{kr,m} r_{kr}^{-\alpha} P_{k,m}}{g_{0r,m} r_{0r}^{-\alpha} P_{0,m} \gamma_{d,m} + N_{r,m} w_m} > \delta_{\mathrm{m}}^{\mathrm{th}}\right), \\
&\overset{(a)}{\approx} \mathbb{P}\left(\frac{g_{k0} r_{k0}^{-\alpha} P_{k,m}}{g_{SI} P_0} > \delta_{\mathrm{m}}^{\mathrm{th}}\right) \mathbb{P}\left(\frac{g_{0r,m} r_{0r}^{-\alpha} P_{0,m} \gamma_{r,m} + g_{kr,m} r_{kr}^{-\alpha} P_{k,m}}{g_{0r,m} r_{0r}^{-\alpha} P_{0,m} \gamma_{d,m}} > \delta_{\mathrm{m}}^{\mathrm{th}}\right), \\
&= \mathbb{P}\left(g_{k0} > \frac{g_{SI} P_{0,m} \delta_m^{th} r_{k0}^{\alpha}}{P_{k,m}}\right) \mathbb{P}\left(g_{kr,m} > \mathrm{A}\right), \\
&= \mathbb{E}_{g_{\mathrm{SI}}}\left[\exp\left(-\frac{g_{SI} P_{0,m} \delta_m^{th} r_{k0}^{\alpha}}{P_{k,m}}\right)\right] \begin{cases} \mathbb{E}_{g_{0r,m}}\left[\exp(-\mathrm{A})\right], & \dfrac{\gamma_{r,m}}{\gamma_{d,m}} < \delta_m^{th}, \\ 1, & \dfrac{\gamma_{r,m}}{\gamma_{d,m}} > \delta_m^{th}, \end{cases} \\
&= \begin{cases} \dfrac{P_{k,m}}{P_{k,m} + P_{0,m} \delta_m^{th} r_{k0}^{\alpha} \sigma_{SI}^2} \dfrac{r_{kr}^{-\alpha} P_{k,m}}{r_{0r}^{-\alpha} P_{0,m} (\delta_m^{th} \gamma_{d,m} - \gamma_{r,m}) + r_{kr}^{-\alpha} P_{k,m}}, & \dfrac{\gamma_{r,m}}{\gamma_{d,m}} < \delta_m^{th}, \\ \dfrac{P_{k,m}}{P_{k,m} + P_{0,m} \delta_m^{th} r_{k0}^{\alpha} \sigma_{SI}^2}, & \dfrac{\gamma_{r,m}}{\gamma_{d,m}} > \delta_m^{th}, \end{cases}
\end{aligned} \tag{2}$$

where $A \triangleq \dfrac{g_{0r,m} r_{0r}^{-\alpha} P_{0,m} (\delta_m^{th} \gamma_{d,m} - \gamma_{r,m})}{r_{kr}^{-\alpha} P_{k,m}}$. Step (a) accesses from the interference-limited consideration.

B. Successful SIC Probability for Case I

If the SINR at $UE_{d,m}$ for decoding the signal intended for $UE_{r,m}$ is greater than the threshold, the SIC is supposed to be successful. Therefore, $S_{SIC,1}$ can be formulated in closed-form as,

$$\begin{aligned}
S_{SIC,1} &= \mathbb{P}\left[\frac{|h_{0d,m}|^2 P_{0,m} \gamma_{r,m} + |h_{kd,m}|^2 P_{k,m}}{|h_{0d,m}|^2 P_{0,m} \gamma_{d,m} + N_{d,m} w_m} > \delta_m^{th}\right], \\
&= \mathbb{P}\left[\frac{g_{0d,m} r_{0d}^{-\alpha} P_{0,m} \gamma_{r,m} + g_{kd,m} r_{kd}^{-\alpha} P_{k,m}}{g_{0d,m} r_{0d}^{-\alpha} P_{0,m} \gamma_{d,m} + N_{d,m} w_m} > \delta_m^{th}\right], \\
&\approx \mathbb{P}\left[g_{kd,m} > \frac{g_{0d,m} r_{0d}^{-\alpha} P_{0,m} (\delta_m^{th} \gamma_{d,m} - \gamma_{r,m})}{r_{kd}^{-\alpha} P_{k,m}}\right], \\
&= \begin{cases} \mathbb{E}_{g_{0d,m}}\left[e^{-\frac{g_{0d,m} r_{0d}^{-\alpha} P_{0,m} (\delta_m^{th} \gamma_{d,m} - \gamma_{r,m})}{r_{kd}^{-\alpha} P_{k,m}}}\right], & \dfrac{\gamma_{r,m}}{\gamma_{d,m}} < \delta_m^{th}, \\ 1, & \dfrac{\gamma_{r,m}}{\gamma_{d,m}} > \delta_m^{th}, \end{cases} \\
&= \begin{cases} \dfrac{r_{kd}^{-\alpha} P_{k,m}}{r_{0d}^{-\alpha} P_{0,m} (\delta_m^{th} \gamma_{d,m} - \gamma_{r,m}) + r_{kd}^{-\alpha} P_{k,m}}, & \dfrac{\gamma_{r,m}}{\gamma_{d,m}} < \delta_m^{th}, \\ 1, & \dfrac{\gamma_{r,m}}{\gamma_{d,m}} > \delta_m^{th}. \end{cases}
\end{aligned} \tag{3}$$

C. Successful Transmission Probability for Case II

In Case II where $\mathbb{E}\{|h_{0r,m}|^2\}>\mathbb{E}\{|h_{0d,m}|^2\}$, $UE_{r,m}$ will be involved with SIC. $UE_{d,m}$ needs to decode the desired signal $x_{i,m}$ while treating the signal $x_{j,m}$ which intended for $UE_{r,m}$ as noise. Therefore, at this situation, the successful transmission probability for $UE_{d,m}$, i.e., $T_{d,m,2}$, is derived as,

$$
\begin{aligned}
&T_{d,m,2}=\mathbb{P}\left(\frac{|h_{0d,m}|^2P_{0,m}\gamma_{d,m}}{|h_{0d,m}|^2P_{0,m}\gamma_{r,m}+|h_{kd,m}|^2P_{k,m}+N_{d,m}w_m}>\delta_m^{th}\right),\\
&\approx\mathbb{P}\left(\frac{g_{0d,m}r_{0d}^{-\alpha}P_{0,m}\gamma_{d,m}}{g_{0d,m}r_{0d}^{-\alpha}P_{0,m}\gamma_{r,m}+g_{kd,m}r_{kd,m}^{-\alpha}P_{k,m}}>\delta_m^{th}\right),\\
&=\begin{cases}\mathbb{P}\left[g_{0d,m}>\dfrac{g_{kd,m}r_{kd}^{-\alpha}P_{k,m}\delta_m^{th}}{r_{0d}^{-\alpha}P_{0,m}(\gamma_{d,m}-\delta_m^{th}\gamma_{r,m})}\right], & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}>\delta_m^{th},\\
\mathbb{P}\left[g_{0d,m}<\dfrac{g_{kd,m}r_{kd}^{-\alpha}P_{k,m}\delta_m^{th}}{r_{0d}^{-\alpha}P_{0,m}(\gamma_{d,m}-\delta_m^{th}\gamma_{r,m})}\right], & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}<\delta_m^{th},\end{cases}\\
&=\begin{cases}\mathbb{E}_{g_{kd,m}}\left[\exp\left(-\dfrac{g_{kd,m}r_{kd}^{-\alpha}P_{k,m}\delta_m^{th}}{r_{0d}^{-\alpha}P_{0,m}(\gamma_{d,m}-\delta_m^{th}\gamma_{r,m})}\right)\right], & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}>\delta_m^{th},\\
0, & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}<\delta_m^{th},\end{cases}\\
&=\begin{cases}\dfrac{r_{0d}^{-\alpha}P_{0,m}(\gamma_{d,m}-\delta_m^{th}\gamma_{r,m})}{r_{kd}^{-\alpha}P_{k,m}\delta_m^{th}+r_{0d}^{-\alpha}P_{0,m}(\gamma_{d,m}-\delta_m^{th}\gamma_{r,m})}, & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}>\delta_m^{th},\\
0, & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}<\delta_m^{th}.\end{cases}
\end{aligned}
\tag{4}
$$

As for the $UE_{r,m}$, the successful transmission probability after successful SIC can be formulated as,

$$
\begin{aligned}
T_{r,m,2}=&\mathbb{P}\left[\min\left(\xi_{r,m}^{0},\xi_{r,m}\right)>\delta_{\mathrm{m}}^{\mathrm{th}}\right],\\
=&\mathbb{P}\left(\frac{g_{k0}r_{k0}^{-\alpha}P_{k,m}}{g_{SI}P_{0,m}+N_0w_m}>\delta_{\mathrm{m}}^{\mathrm{th}}\right)\mathbb{P}\left(\frac{g_{0r,m}r_{0r}^{-\alpha}P_{0,m}\gamma_{r,m}+g_{kr,m}r_{kr}^{-\alpha}P_{k,m}}{N_{r,m}w_m}>\delta_{\mathrm{m}}^{\mathrm{th}}\right),\\
\approx&\mathbb{P}\left(\frac{g_{k0}r_{k0}^{-\alpha}P_{k,m}}{g_{SI}P_{0,m}}>\delta_{\mathrm{m}}^{\mathrm{th}}\right)\mathbb{P}\left(\frac{g_{0r,m}r_{0r}^{-\alpha}P_{0,m}\gamma_{r,m}+g_{kr,m}r_{kr}^{-\alpha}P_{k,m}}{N_{r,m}w_m}>\delta_{\mathrm{m}}^{\mathrm{th}}\right),\\
=&\mathbb{P}\left(g_{k0}>\frac{g_{SI}P_{0,m}\delta_m^{th}r_{k0}^{\alpha}}{P_{k,m}}\right)\mathbb{P}\left(g_{0r,m}>\frac{\delta_m^{th}N_{r,m}w_m-g_{kr,m}r_{kr}^{-\alpha}P_{k,m}}{r_{0r}^{-\alpha}P_{0,m}\gamma_{r,m}}\right),\\
=&\mathbb{E}_{g_{\mathrm{SI}}}\left[\exp\left(-\frac{g_{SI}P_{0,m}\delta_m^{th}r_{k0}^{\alpha}}{P_{k,m}}\right)\right]\cdot\\
&\left[\mathbb{P}\left(g_{0r,m}>\mathrm{B}|\mathrm{B}\geq 0\right)\mathbb{P}\left(B\geq 0\right)+\mathbb{P}\left(g_{0r,m}>\mathrm{B}|\mathrm{B}<0\right)\mathbb{P}\left(B<0\right)\right],\\
=&\frac{P_{k,m}}{P_{k,m}+P_{0,m}\delta_m^{th}r_{k0}^{\alpha}\sigma_{SI}^2}\cdot\\
&\left[\int_0^{\frac{\delta_m^{th}N_{r,m}w_m}{r_{kr}^{-\alpha}P_{k,m}}}e^{(-B-g_{kr,m})}\mathrm{d}g_{kr,m}+\int_{\frac{\delta_m^{th}N_{r,m}w_m}{r_{kr}^{-\alpha}P_{k,m}}}^{\infty}1\cdot e^{-g_{kr,m}}\mathrm{d}g_{kr,m}\right],\\
=&\frac{P_{k,m}}{P_{k,m}+P_{0,m}\delta_m^{th}r_{k0}^{\alpha}\sigma_{SI}^2}\cdot\\
&\left[\frac{r_{0r}^{-\alpha}P_{0,m}\gamma_{r,m}}{r_{kr}^{-\alpha}P_{k,m}-r_{0r}^{-\alpha}P_{0,m}\gamma_{r,m}}\left(e^{\frac{-\delta_m^{th}N_{r,m}w_m}{r_{kr}^{-\alpha}P_{k,m}}}-e^{\frac{-\delta_m^{th}N_{r,m}w_m}{r_{0r}^{-\alpha}P_{0,m}\gamma_{r,m}}}\right)+e^{\frac{-\delta_m^{th}N_{r,m}w_m}{r_{kr}^{-\alpha}P_{k,m}}}\right],
\end{aligned}
\tag{5}
$$

where $B\triangleq\dfrac{\delta_m^{th}N_{r,m}w_m-g_{kr,m}r_{kr}^{-\alpha}P_{k,m}}{r_{0r}^{-\alpha}P_{0,m}\gamma_{r,m}}$ is defined.

D. Successful SIC Probability for Case II

The successful SIC probability in Case II, i.e., $S_{SIC,2}$ can be formulated in closed-form as,

$$
\begin{aligned}
S_{SIC,2}=&\mathbb{P}\left[\frac{|h_{0r,m}|^2P_{0,m}\gamma_{d,m}}{|h_{0r,m}|^2P_{0,m}\gamma_{r,m}+|h_{kr,m}|^2P_{k,m}+N_{r,m}w_m}>\delta_m^{th}\right],\\
\approx&\mathbb{P}\left[\frac{g_{0r,m}r_{0r}^{-\alpha}P_{0,m}\gamma_{d,m}}{g_{0r,m}r_{0r}^{-\alpha}P_{0,m}\gamma_{r,m}+g_{kr,m}r_{kr}^{-\alpha}P_{k,m}}>\delta_m^{th}\right],\\
=&\begin{cases}\mathbb{P}\left(g_{0r,m}>\dfrac{\delta_m^{th}g_{kr,m}r_{kr}^{-\alpha}P_{k,m}}{r_{0r}^{-\alpha}P_{0,m}(\gamma_{d,m}-\delta_m^{th}\gamma_{r,m})}\right), & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}>\delta_m^{th},\\ \mathbb{P}\left(g_{0r,m}<\dfrac{\delta_m^{th}g_{kr,m}r_{kr}^{-\alpha}P_{k,m}}{r_{0r}^{-\alpha}P_{0,m}(\gamma_{d,m}-\delta_m^{th}\gamma_{r,m})}\right), & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}<\delta_m^{th},\end{cases}\\
=&\begin{cases}\dfrac{r_{0r}^{-\alpha}P_{0,m}(\gamma_{d,m}-\delta_m^{th}\gamma_{r,m})}{\delta_m^{th}r_{kr}^{-\alpha}P_{k,m}+r_{0r}^{-\alpha}P_{0,m}(\gamma_{d,m}-\delta_m^{th}\gamma_{r,m})}, & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}>\delta_m^{th},\\ 0, & \dfrac{\gamma_{d,m}}{\gamma_{r,m}}<\delta_m^{th}.\end{cases}
\end{aligned}
\tag{6}
$$