Abstract

Communication reliability improving is one of most important research requirements in cognitive networks, as 5G communications technology rapidly develop nowadays. In this paper, we propose generalized optimal cloud-based region relays subsets paring model in underlay dual-hop cognitive networks, this unified model reveals three relays nodes characteristics of cloud-based cooperative networks in the nearby area- $A$ subset, only needs receiving for first hop, $B$ subset, just receive and forward, $C$ subset, only forwarding. In addition, this generalized model can be converted into various classical relay selection algorithms when $A$, $B$ and $C$ subsets are taken as special selection values [Table II]. Furthermore, we put forward optimal relays subsets pairings and replacement algorithm flowchart to improve minimum outage probability (OP) for communication reliability, and prove that optimal relays subsets pairings ($A$, $B$, $C$) will better guarantee reliability of communication, comparing other popular relays selection schemes. Simulation results show that optimal relays paired subsets are exist and this generalized algorithm enormously reduces OP, comparing other selection algorithms.

Index Terms
Cognitive networks, generalized relays selection model, cloud-based relays, optimal subsets pairings.

I. INTRODUCTION

Recently, as wireless communication develop rapidly and higher communication quality is demanded, Internet of Things (IoT) [1], [2] is regarded as large networks which merge various sensors devices and 5G networks to realize interconnection among man, machine and material [3]-[7]. On the other hand, 5G communications have notable characteristics on faster speed data transmission, lower end to end latency and higher coverage compared to 4G communications. Hence, IoT based on cognitive networks [8], [9] have close connection with cognitive heterogeneous networks [10], device-to-device communication [11], cooperative hybrid satellite and terrestrial communication scenario [12] and so on. Besides, a large number of communication technologies are widely used in cognitive networks, such as, cooperative communications, non-orthogonal multiple access [13], [14], full duplex [15], physical layer security technology [16], to incredibly improve validity, reliability and security in real wireless communication systems.

Cooperative communications with amplify-and-forward (AF) and decode-and-forward (DF) relays selection have been extensively investigated in a variety of cognitive radio scenarios, for instance, interweave, overlay and underlay [17]. It is important that how to appropriately select relays nodes to optimize spectrum efficiency, enhance availability and improve security in cognitive radio networks. So far, one of most popular relay selection is best signal-to-noise selection, [18] considers choosing opportunistic full-duplex AF relay in underlay cognitive networks to analyze symbol error probability (SEP) and upper bound of outage channel capacity of secondary user. [19] investigates outage performance by employing maximum ratio combining (MRC) and selection combining (SC) by selecting opportunistic relay in cognitive underlay networks. Next, N-th best relay selection is employed under specific practical cognitive system. [20] computes diversity orders
by using $N$-th best relay selection in cooperative cognitive system. [21] gives performance evaluation in cognitive underlay networks with $N$-th best DF relay. In addition, partial relays selection [22], [23]-[28] and all relays selection are discussed to improve communication quality. [29] minimizes sum bit error rate (BER) with one or two partial relays selection algorithm in two-way relay network. [30] considers selecting near partial relays with distribution estimation scheme for cooperative Single-Carrier Frequency-Domain Equalization to minimum processing time. [31] analyzes error rate and proposes fair power allocation plan under generic noise and interference with partial relays selection. And relays subsets selection is investigated in [32], [33], [34] presents multiple sources to multiple destinations with relays subset pairs to obtain maximum spatial diversity on account of max-min criterion. [35] proposes optimized relays subset to realize beamforming [36] under optimal thresholds constraints. Selecting relays with buffers are also adopted to improve the throughput of cooperative system, [37] considers max-max half-duplex buffer relays selection scheme to analyze outage probability (OP) and symbol error probability. [38] investigates dual-hop half-duplex buffer relay selection algorithm, and compares it with other non-buffer and buffer relay selections in the performance of average rate and symbol error rate (SER).

On the other hand, hops in different cooperative communications scenarios are very crucial factors for relays selection. Dual-hop and multiple hops [39] are main critical and studied problems for optimizing transmission quality, and dual-hop relays selection are more representative than multiple hops selection, as the latter research problem can be transformed to the former matter. There are many typical and important research algorithms for dual-hop relays selection in cooperative systems, for example, [40] proposes a cross entropy (CE) method to reduce computational cost and maintain achievable rate in two-way MIMO relays systems. [41] studies relays selection and power allocation in two-way adaptive cognitive networks to optimize OP under constraint of OP of primary users. [42] proposes power allocation optimization issue to minimize OP in multi-source and multi-relay
dual-hop system. [43] presents novel dual-hop AF relay selection rules to improve performance of secondary users, compared to other classical relay selection methods. [44] jointly conducts relay selection and spectrum allocation to optimize achievable rate in cognitive MIMO dual-hop relay networks.

Problems for discussions above:

1) Schemes of relays nodes deployment. Aiming at issues of deployment of a large number of relays nodes in 5G cognitive networks, how to increase date transmission rate and ensure reliability relays nodes is the most important item, hence, more effective algorithms of relays selection need to be put forward to improve communication transmission quality.

2) Simplification of selection algorithms. The relay nodes selection methods are different at present in a variety of communication scenarios and systems, and selection method is very simplicity, therefore, one generalized selection algorithms is demanded to satisfy various communication requirements in specific cognitive networks.

3) Performance improvement against classical relays selection. Dual-hop relay selection methods listed above, such as, best relay selection, N-th best relay selection, partial relays selection and so on, have not been optimized under center restraints. Furthermore, aiming at performance optimization in cooperative relays selection, the objections of optimization of existing researches are very simple and closed-form optimal and sub-optimal expressions are hard to obtain in more complex cooperative communication systems which consider more crucial factors, hence, it is always to seek non close-form solutions.

Main contributions:

· This paper proposes cloud-based relays selection in the nearby area for dual-hop cooperative communications to optimize OP for problem 1. This cloud-based selection scheme is totally different from [45]-[47] (considering concrete condition and constraints of relays, then select related relays as cloud relays) and [48]-[50] (individual RF/FSO relay node selection for all relays
in cloud), proposed relays cloud are multiple relays arrangement that are selected as the result of relays nodes paring and replacement in the nearby area. Besides cloud servers are located in the center position of cloud-based networks, in order to reduce time-delay feedback between relays nodes and cloud servers. It can be concluded that taking into consider relays subset selection in specific region to optimized and sub-optimized communication transmission, is more effective than single or multiple relays selection in realistic cooperative networks. In this paper, OP of optimization relays subsets selection are calculated in cloud-based region, and performance of proposed algorithms are compared to other classical selection methods.

- Generalized two-way cloud-based region optimal relays nodes subsets selection algorithm is proposed to solve problem 2. Unified two-way selection models have been presented and each hop is respectively optimized. The general models can be converted into all sorts of conventional relays selection algorithms, when $A$, $B$, $C$ subsets are taken as special values [Table II]. Consequently, proposed models will replace classical selection models discussed above for relays selection in certain region. On the other hand, relays subsets pairings with each optimum hop are chosen under constraints of total signal-to-interference plus noise ratio (SINR) of relays nodes.

- Features of $A$, $B$, $C$ subsets are revealed and optimal relays subsets parings are obtained for problems 1-3. Like Fig.1 in [20], [26], [27] and [51], it is concluded that maybe there are many pairings with different numbers of relays to achieve same OP under equal SINR constraints. Optimal relays subsets parings have been proved existence, and algorithm flow of subsets selection and relays replacement in each subset are presented to search optimal $A$, $B$, $C$ subsets infinitely. Furthermore, the proposed cloud-based region relays subsets pairings method has greatly reduced computation complexity of searching, and creatively solves the problem that close form expressions are hard to obtain with ideology of subsets match. Simulations show that performance of optimum subsets has far exceeded than other classical schemes.
II. PROPOSED SYSTEM MODEL AND SUBSET SELECTION

We consider underlay cognitive radios in dual-hop cooperative cognitive networks, as shown in Fig.1, the system contains one secondary user transmission source (S\textsubscript{T}), \( N \) relays nodes \( \{R_i\} = \{R_i | 1 \leq i \leq N\} \) and cloud servers, one secondary user destination (D), one primary transmission source (P\textsubscript{T}), one primary receiver (P\textsubscript{R}). The S\textsubscript{T}, D, P\textsubscript{T}, P\textsubscript{R} and \( R_i \) are half-duplex with one antenna. The networks of secondary and primary are subject to independent identically distributed (i.i.d.) Rayleigh fading channels, assume the channel coefficients of the links for S\textsubscript{T} \( \rightarrow \) \( R_i \), S\textsubscript{T} \( \rightarrow \) P\textsubscript{R} , P\textsubscript{T} \( \rightarrow \) R\textsubscript{i}, P\textsubscript{T} \( \rightarrow \) D and R\textsubscript{i} \( \rightarrow \) D are defined as \( h_{STR} \), \( h_{STR} \), \( h_{PTR} \), \( h_{PPT} \) and \( h_{RD} \), relays nodes for \( R_i \) is DF. In Fig.1, assume \( \{R_i\} \) is defined as subset with relays only receive signals from S\textsubscript{T}, \( \{R_g\} \) is defined as subset with relays receive signal from S\textsubscript{T} and forward to D, \( \{R_c\} \) is defined as subset with relays only forward signal to D. Hence, in order to effectively transmit signal from S\textsubscript{T} to D, it should be

\[
\{\{R_i\}, \{R_g\}, \{R_c\}\} \subseteq \{R_N\} \\
\begin{cases}
\{R_g\} \neq \emptyset \text{ and } \{R_c\} \neq \emptyset, & \text{if } \{R_g\} = \emptyset \\
\{R_g\} = \emptyset \text{ or not} \\
\{R_c\} = \emptyset \text{ or not} & \text{if } \{R_g\} \neq \emptyset \\
\{R_g\} = \emptyset \text{ and } \{R_c\} = \emptyset
\end{cases}
\] (1)

The distances are far longer for S\textsubscript{T} \( \rightarrow \{R_N\} \) and \( \{R_N\} \rightarrow \) D than distances between \( \{R_N\} \) and cloud servers in the nearby area for relays cloud, and cloud servers are deployed at the center location in cloud-based relays networks, so as to reduce feedback time like relays selection in cloud-based communications networks with RF/FSO [48]-[50], hence, feedback time can be neglected because of distances between relays nodes and cloud-based servers are relatively short.
Communication process is shown as Fig.2, firstly users of secondary source and destination send signals to \( \{R_s\} \) simultaneously to detect the channel coefficients of links, secondly secondary transmission source sends signals to \( \{R_s\} \) and \( \{R_s\} \) send signals to cloud servers together, thirdly after computing and selecting optimized relays subsets \( \{R_s\} \), \( \{R_s\} \) and \( \{R_s\} \), then cloud servers give feedback signals to selected relays, last relays in subsets \( \{R_s\} \) and \( \{R_s\} \) forward signals to destination.

Furthermore, optimized selected relays subsets are depicted in Fig.3, we assume \( \{R_s\} \) contains \( i \) relays, \( \{R_s\} \) contains \( j \) relays, \( \{R_s\} \) contains \( N-i-j \) relays,

\[
\begin{align*}
\{R_s\} &= \{R_s \mid 1 \leq k \leq i\} \\
\{R_s\} &= \{R_s \mid i+1 \leq k \leq i+j\} \\
\{R_s\} &= \{R_s \mid i+j+1 \leq k \leq N\}
\end{align*}
\]
We assume signal of $S_T$ is $x_s$, signal of $P_T$ is $x_p$, $P_{ST}$ is maximum transmission power of $S_T$, $P_{PT}$ is maximum transmission power of $P_T$, $n_R$ is additive white Gaussian noise of relay, then received signal of $R$ is given by

$$y_{SR} = \sqrt{P_{ST}} h_{STR} x_s + \sqrt{P_{PT}} h_{PTR} x_p + n_R, R_i \subseteq A + B$$

(3)

When relays receive feedback of cloud servers, we assume for relay $R_j$, $P_R$ is maximum transmission power, $n_D$ is additive white Gaussian noise (AWGN) of D, received signal of D is given by

$$y_{RD} = \sqrt{P_R} h_{R,D} x_s + \sqrt{P_{PT}} h_{PRD} x_p + n_D, R_j \subseteq B + C$$

(4)

For relay $R_i$, if $R_i$ receive signal and forward, SINR of first hop and second hop are respectively $\delta_{STR}$ and $\delta_{R,D}$, minimum SINR is given by

$$\delta_i = \min(\delta_{STR}, \delta_{R,D})$$

(5a)

$$\approx \frac{\delta_{STR}}{\delta_{STR} + \delta_{R,D}}$$

(5b)

TABLE I

SYMBOLS DEFINITION
In this section, minimum OP with relays subsets have been derived respectively for two-way simultaneous optimization, and \( i \)-th OP for first and second hop with different optimized subsets also have been given by. Further advantage of proposed system for relays arrangement is analyzed.

**Lemma 1** We assume maximum permissible interference power is \( Q_{\text{PR}} \) for \( S_T \), \( N_0 \) is the noise power of AWGN, when subsets \( A+B \) are selected in the first hop, for selected \( R_i \), if \( R_i \subseteq A+B \), optimized OP is expressed as (54).

**Proof**: See proof of **Lemma 1** in Appendix.

**Lemma 2** When subsets \( B+C \) are selected in the second hop, for selected \( R_j \), if \( R_j \subseteq B+C \), we assume maximum permissible interference power is \( Q_{\text{PR}} \), optimized OP is expressed by (57) and (62).

**Proof**: See proof of **Lemma 2** in Appendix.

Based on **Lemma 1** and **Lemma 2**, for first hop \( S_t \rightarrow \{R_i\} \), assume \( \{R_i\} (\{R_i\} \subseteq \{R_n\}) \) are represented as \( \{R_1, R_2, \ldots, R_i\} \) in descending order of SINR, SINR for \( \{R_i\} \) are represented as \( \{\delta_{1-i}, \delta_{2-i}, \ldots, \delta_{i-i}\} \), CDF for \( \{R_i\} \) are \( \{F^i(z), F_{R_1}(z), \ldots, F_{R_i}(z)\} \). For second hop \( \{R_i\} \rightarrow D \), assume \( \{R_j\} (\{R_j\} \subseteq \{R_n\}) \) are represented as \( \{R_1, R_2, \ldots, R_j\} \) in descending order of SINR, SINR for \( \{R_j\} \) are represented as \( \{\delta_{1-j}, \delta_{2-j}, \ldots, \delta_{j-j}\} \), CDF for \( \{R_j\} \) are \( \{G^j(z), G_{R_1}(z), \ldots, G_{R_j}(z)\} \).

### TABLE II

| \( R_i \) : Relay \( i \) | \( \{R_n\} \) : \( N \) relays | \( A, B, C \) : Relays subsets |
|--------------------------|-----------------|-------------------------|
| \( A^*, B^*, C^* \) : Optimized relays subsets | \( \delta_0 \) : Threshold of SINR | \( \delta_\text{th} \) : Total SINR |
| \( \delta_{i-th} \) : \( i \)-th SINR in descending order | \( f(.) \) : Probability Density Function (PDF) | \( F(.) \) : Cumulative Distribution Function (CDF) |
| \( \|h\| \) : Distance of \( h \) | \( |D| \) : Relay number of section \( D \) | \( \gamma_r \) : Signal-to-noise (SNR) in |

III. **OPTIMAL OUTAGE PROBABILITY OF CLOUD-BASED REGION RELAYS SUBSETS SELECTION**
Lemma 3 For subsets $A, B, C$, we assume $i$-th SINR relay $R_i$ in $\{R_n\}$ and relays are selected mutually independently with optimized subsets $A' + B'$ in first hop, OP of $R_i$ is derived as (6), and OP with $A' + B'$ is derived as (8). Similarly, $j$-th SINR relay $R_j$ in $\{R_n\}$ and relays are mutually independently to forward with optimized subsets $B' + C'$ in second hop, OP of $R_j$ is given by (9), and OP with $B' + C'$ is given by (11).

Proof: For first hop, when optimized subsets $A' + B'$ are selected, this moment $B'$ only receive signal from secondary transmission source, as $R_i \subset A' + B'$ and SINR of $R_i$ is $\delta_{i-th}$, we assume PDF of $i$-th $R_i$ is $f_{i-out}^{\delta_{i-th}}(z)$, CDF of $i$-th $R_i$ is given by

$$F_{1-out}^{i-th}(z) = \int_0^z f_{1-out}^{\delta_{i-th}}(z)dz$$

(6)

Because $A' + B'$ independently receive signal and with the aid of [20, 52], we get PDF of $i$-th $R_i$ as

$$f_{1-out}^{\delta_{i-th}}(z) = \sum_{i=1}^{I} f_{i}^R(z) \sum_{\{R_i \subset A', R_j \subset B'\}} \prod_{k=1}^{I} F_{k}^R(z) \prod_{k=1}^{J} (1-F_{k}^R(z))$$

(7)

Hence, with optimized subsets $A' + B'$, OP of first hop is derived as

$$F_{1-out}^{A' + B'}(\delta) = \prod_{R_i \subset A' + B'} F_{1-out}^{R_i}(\delta_{i-th})$$

(8)

Similarly, for second hop as $R_j \subset A' + B'$ and SINR of $R_j$ is $\delta_{j-th}$, CDF of $j$-th $R_j$ is given by

$$F_{2-out}^{j-th}(z) = \int_0^z f_{2-out}^{\delta_{j-th}}(z)dz$$

(9)

This moment $B'$ only send signal to secondary destination, we assume PDF $R_j$ of is $f_{2-out}^{\delta_{j-th}}(z)$, we get PDF of $R_j$ as

$$f_{2-out}^{j-th}(z) = \sum_{i=1}^{J} g_{j}^R(z) \sum_{\{R_j \subset B', R_k \subset C\}} \prod_{k=1}^{J} G_{k}^R(z) \prod_{k=N-j+1}^{J} (1-G_{k}^R(z))$$

(10)

OP of second hop with $B' + C'$ is derived as

$$F_{2-out}^{B' + C'}(\delta) = \prod_{R_i \subset B' + C'} F_{2-out}^{R_i}(\delta_{j-th})$$

(11)

where $f(.)$ and $g(.)$ are respectively PDF of $F(.)$ and $G(.)$. 
Lemma 4 Unlike conditional underlay cooperative networks in Fig.4, it should be considered under the constraint of $\|h_1\| > \|h_2\|$ or $\|h_1\| \gg \|h_2\|$ to have better communications performance [7], [17]-[19]. Proposed regional relays subsets pairings selection algorithm will no longer subject to $\|h_1\| > \|h_2\|$ or $\|h_1\| \gg \|h_2\|$.

![Diagram of Conditional underlay transmission networks](image)

Fig.4 Conditional underlay transmission networks (s.t. $\|h_1\| > \|h_2\|$ or $\|h_1\| \gg \|h_2\|$)

**Proof:** For proposed two-way optimization for relays subsets pairings selection algorithm, we minimize OP as

$$\arg \min (\delta_{STD}) = \arg \min (\bigcup_{\mathcal{A}', \mathcal{B}', \mathcal{C}'} \delta_{ST(\mathcal{R}')} \cup \bigcup_{\mathcal{D}'} \delta_{R'D})$$

(12)

Computing OP as

$$\arg \min (\delta_{STD}) = \arg \min (\bigcup_{\mathcal{A}', \mathcal{B}', \mathcal{C}'} \delta_{ST(\mathcal{R}')} \cup \bigcup_{\mathcal{D}'} \delta_{R'D}) \leq \delta_{th}$$

(13a)

$$= \arg (1 - Pr(\min (\bigcup_{\mathcal{A}', \mathcal{B}', \mathcal{C}'} \delta_{ST(\mathcal{R}')} \cup \bigcup_{\mathcal{D}'} \delta_{R'D}) \geq \delta_{th}))$$

(13b)

By considering Lemma1-Lemma3, we obtain

$$\arg \min (\delta_{STD}) = \arg (1 - (1 - \prod_{\mathcal{R}'} (1 - \prod_{\mathcal{A}', \mathcal{B}', \mathcal{C}'} \delta_{ST(\mathcal{R}'} \prod_{\mathcal{D}'} (1 - \prod_{\mathcal{A}', \mathcal{B}', \mathcal{C}'} \delta_{R'D}))$$

(14)

In (14), we find $\{\mathcal{R}'\}$ and $\{\mathcal{R}^*\}$ are not exactly same, besides OP for first hop and second hop are computed respectively, hence, for proposed algorithm $\|h_1\| \geq \|h_2\|$ and $\|h_1\| \leq \|h_2\|$ are valid to improve flexibility of arrangement of primary users. In addition, we assume $\{\mathcal{R}_x\} \subseteq \{\mathcal{R}_y\}$, with the aid of (1), comparing to conditional relays with receiving and forward, in (14) OP will be reduced as
As shown in Fig. 5, the framework flow of optimal relays subsets pairings and replacement, finite relays subsets A, B, C will be searched (Searching complexity is contrasted after Lemma 8). For relays \( \{R_x\} \) ( \( \{R_n, n=1,2,\ldots,N\} \)), \( \{R_n\} \) are arranged in ascending order of SINR, now divide \( \{R_n\} \) into \( K \) sections as \( \{T_i \mid 1 \leq i \leq K\} \), and sections are represented as

\[
\{T_K\} = \bigcup_{i=1}^{K} \bigcup_{m=1}^{l_i} R_m \mid l_1 \leq l_2 \leq \ldots \leq l_{K+1}, l_1 = 1, l_{K+1} = N
\]

Then selecting same number of relays from each section to form a subset, and number of each section is defined as \( \text{Num}(T_i) = l_{i+1} - l_i \), as shown in Fig. 6 because relays in section with higher SINR provide lower OP, and threshold of total SINR is constant, hence in order to effectively select relays, we have

\[
\text{Num}(T_i) = l_{i+1} - l_i
\]

s.t. \( \text{Num}(T_{i+1}) \geq \text{Num}(T_i) \)
Lemma 5 (Relays subsets selection algorithm in \(A, B, C\)) We divide \(N\) relays \(\{R_i\}\) into \(K\) sections, then sections are represented as

\[
T_K = \bigcup_{i=1}^{K} \left( \text{Num}(T_{i+1}) R_{i+1} + R_{i+1} \right)
\]  

(20)

where \(T_i = (R_1, R_2, \ldots, R_p)\) and \(K \geq 2\), in addition, SINR of relays should satisfy

\[
\delta_{p_{i+1}} \leq \delta_{p_i} + \delta_{p_i} \leq \delta_{p_{i+1}}
\]  

(21)

**Proof:** On account of discussions of sections partition above, as higher SINR is corresponding to lower OP, under constraints of total SINR for \(\sum \delta_{i_k} \leq \delta_{th}\), now select \(M\) relays in each section to form one subset, then we have

\[
\sum_{i_k} \sum_{R_i \subseteq T_{i_k}} \delta_{R_i} \leq \delta_{th}
\]  

(22)

Furthermore, when divided sections is \(D\) and \(D > K\), now we consider dividing \(D\) sections into \(D - K\) sections, and \(MD = D - K\), we reconsider dividing sections with low SINR to make \(\sum \delta_{i_k}\) more closer to \(\delta_{th}\), we assume re-dividing sections are defined as \(T_L = (|L| = |D|)\), total SINR is given by

\[
\sum_{i_k \subseteq T_L} \sum_{R_i \subseteq T_{i_k}} \delta_{R_i} + \sum_{i_k \subseteq T_L} \sum_{R_i \subseteq T_{i_k}} \delta_{R_i} \leq \delta_{th}
\]  

(23)

**Corollary 1** (Relays subsets replacement algorithm in \(A, B, C\)): In view of Lemma 5, (22) and (23), when \(M=1\), in Lemma 5 there are \(D\) divided sections, selected relays are expressed as \(\bigcup_{i=1}^{D} R_i\), corresponding SINR are \(\{\delta_i | 1 \leq i \leq D\}\), then \(D\) sections will be readjusted as
\[
\{{T_D}\} = \bigcup_{i=1}^{D} \bigcup_{m=1}^{l_i} {R_m} \mid R_i \leq R_{i+1}, R_{i+1} < R_{i+2}, l_i = 1, R_{l_i+1} < R_{N}\] (24)

Hence, we have

\[
\arg \min_{\{T_0\}} \prod_{R_i \in T, R_j \in \{T_0\}} F^T (\delta_{R_i}) \] (25)

\[s.t. \sum_{i=1}^{D} \text{Num}(T_i) = N\] (26)

where \(\delta_{R_i}\) is SINR of \(R_i\).

**Proof:** Based on relays partition based on Lemma 5, in order to make OP minimum and reduce selection complexity, hence readjust relays subsets. Because of arrangement order of relays are stationary, positions of readjustment interval are set between two adjacent selected relays. For instance, we assume selected relays \(R_i, R_j\) and \(R_{i+1}\) that are selected from sections \(T_{i-1}, T_i\) and \(T_{i+1}\), we assume relays positions of readjustment are \(R_j (R_i \leq R_j < R_{i+1})\) and \(R_{i+1} (R_i \leq R_{i+1} < R_{i+2})\). Then if readjustment intervals are represented as \(T_{i-1}, T_i\) and \(T_{i+1}\), the following posture should be satisfied

\[
\arg \min_{i=1}^{D} F^{T_i} (\gamma_{i-1}) F^{T_i} (\gamma_i) F^{T_i} (\gamma_{i+1}) \] (27)

More generally, if we readjust \(D\) intervals so that we make OP as far as possible small for each relays sections. We obtain

\[
\arg \min_{\{T_0\}} \prod_{R_i \in T, R_j \in \{T_0\}} F^T (\delta_{R_i}) \] (28)

\[s.t. \sum_{i=1}^{D} \text{Num}(T_i) = N\] (29)

When relays are selected from single subset in \(A, B, C\) for Lemma 5 and Corollary 1, now select relays to make subsets pairings for \(A+B\) and \(B+C\).

**Lemma 6 (Subsets pairings for \(A+B\) and \(B+C\))** We assume \(N\) relays \(\{R_n\}\) and select relays to form \(A, B, C\) subsets, if total SINR is \(\delta_{ab}\), we determine subset \(B\), then determine subset \(C\) subject to certain \(B\).
**Proof:** Firstly, we determine priority of $B$ and $C$, in (45) and (54) when primary interference is constant ($|h_{PT(P_s,s)}|$ and $|h_{PT(P_{dd})}$ are invariant), because of one secondary destination and multiple relays in cooperative networks, for first hop, relays in $B$ is only related to $|h_{ST(R_s,s)}|$, for second hop, after receiving feedback of cloud servers, relays in $B$ and $C$ are related to $|h_{[R_{s},C]}|$, in summary, relays in $B$ have better priority than $C$ as $B$ should receive and forward signal, we assume invariant and selected subset $\{R_T\}$, where from partial relays selection [25]-[27], we get

$$F_{out}(\{R_T\} | \{R_T\} \subset B) = P_r(\min(\delta_{ST(R_s)}, \delta_{[R_s,d]}))$$ (30)

And with (8) and (11) in Lemma 3

$$F_{out}(\{R_T\} | \{R_T\} \subset C) = P_r(\delta_{[R_s,d]}))$$ (31)

Furthermore, with the aid of (15) and (16) in Lemma 4, we obtain

$$F_{out}(\{R_T\} | \{R_T\} \subset B) > F_{out}(\{R_T\} | \{R_T\} \subset C)$$ (32)

Therefore, $B$ should satisfy

$$\sum_{R_T \in B} \delta_{R_T} < \delta_{ab}$$ (33)

$$\sum_{C \supset [R_s]} \delta_{c} \leq \delta_{ab} - \sum_{(R_T \in B \cup [R_s]) \subset [R_s]} \delta_{R_T}$$ (34)

It is noteworthy that for second hop

$$F_{out}(\{B^*\} + \{C^*\}) = F_{out}(\{C^*\} + \{B^*\})$$ (35)

Hence for Fig.7, when searching finite optimal subsets $B^* + C^*$, we get

$$\delta_{R_{B_T}} > \delta_{R_{C_T}} \quad (R_{B_T} \in B, R_{C_T} \in C)$$ (36)
Corollary 2 Continued from Lemma 6, as relays in B have more priority than A and C, relays in C have more priority than A, when B+C are determined, then we select relays for A+B.

Proof: Similar to Lemma 6, A is only related to $|h_{A_0}|^2$ and multiple relays in C are respectively related to $|h_{A_0}|^2$ under different constraints of $Q_{R_{A_0}},$ with each relay, hence when B+C are determined, we select relays to form A according to $S_{T-}\{R_y\},$ we obtain

$$\sum_{A\subset\{R_y\}\cap \{B,C\}} \delta_A \leq \delta_{A_0} - \sum_{\{R_y\}\cap \{B,C\}} \delta_{|R_y|} - \sum_{C\subset\{R_y\}\cap \{B\}} \delta_{C}$$

(37)

To sum up, for finite subsets paring searching, we assume relay $R_i \ (R_i \subset \{R_y\}),$ then we have

$$\begin{align*}
R_i &\subset \{A,B,C,\emptyset\} \\
R_i &\not\subset \{A,\emptyset\} \cap \{C,\emptyset\}
\end{align*}$$

(38)

So for N relays with A, B, C subsets, according to conditional selection method, we have $4^N - 2 * 2^N + 1$ selection pairings, but with the aid of selection algorithm from Lemma 5 to Corollary 2, the computational complexity is given by

$$o(.)=C^{N_{A_0}}_{N_{A_0}} \cdot C^{N_{B_0}}_{N_{B_0}} \cdot C^{N_{C_0}}_{N_{C_0}} \quad \text{if} \quad N_{g_0} = \emptyset, N_{A_0}, N_{C_0} \neq \emptyset$$

(39)

$$s.t. \quad N_{A_0} + N_{g_0} + N_{C_0} = N$$

(40)

where $N_{A_0}, N_{g_0}, N_{C_0}$ represent total relays number of optimized subsets $A', B', C',$ $N_{A_0}, N_{g_0}, N_{C_0}$ represent number of relays selection for each subset in $A', B'$ and $C'.$ Thus it can be seen that proposed algorithm greatly reduces computational complexity of conditional relays subsets selection.

V. PERFORMANCE ANALYSIS AND SIMULATIONS

In this section, we compare proposed generalized optimal cloud-based region two-way subsets pairing algorithm with other classical relays selection methods, shown as Table II, when optimal relays pairing $A^*, B^*, C^*$ are taken as special values, we convert proposed models into classical selection algorithms, which contain best relay selection, $N$-best relay selection, partial relays...
selection and so on. It is concluded that conventional selection algorithms are special cases that can be derived from proposed generalized schemes. Further, we simulate proposed algorithm with multiple relays pairings for different number of relays, besides, scenarios parameters are set as $\sigma_{\alpha}^i = \sigma_{\alpha}^j = \sigma_{\alpha}^k = 1$, $P_{st} = Q_{rs}$, $P_{s} = Q_{rt}$, $\sigma_{\alpha}^i = \sigma_{\alpha}^j = 5$, $N_0 = 1$ and $\delta_0 = 4.8 \text{dB}$. In simulations, in order to evaluate minimum upper bound of OP, for relay $R_i$ ($R_i \subset A+B$) and $R_j$ ($R_j \subset B+C$), with the aid of (5), (8) and (11), we obtain

$$F_{\{A\}+\{B\}+\{C\}}(\min(\delta_{SR}, \delta_{RD})) \leq (F_{\{A\}}(\delta_{STR}), F_{\{B\}}(\delta_{R,D}))$$

$$F_{\{A\}+\{B\}+\{C\}}(\min(\delta_{SR}, \delta_{RD})) \leq (F_{\{B\}}(\delta_{STR}), F_{\{C\}}(\delta_{R,D}))$$

Furthermore, with the help of (6), we get

$$F_{\{A\}+\{B\}+\{C\}}(\min(\delta_{SR}, \delta_{RD})) \leq (F_{\{A\}}(\delta_{STR}), F_{\{B\}}(\delta_{R,D})) \{R_i \in A, R_j \in B, R_k \in C\} \leq A^i + B^j, i \neq 1$$

$$F_{\{A\}+\{B\}+\{C\}}(\min(\delta_{SR}, \delta_{RD})) \leq (F_{\{B\}}(\delta_{STR}), F_{\{C\}}(\delta_{R,D})) \{R_i \in B, R_j \in C, R_k \in A\} \leq A^i + B^j, j \neq 1$$

Fig.8 and Fig.9 illustrate OP versus SINR with two, three and

**TABLE II**

PROPOSED MODEL CONVERTS INTO CLASSICAL MODELS, WHEN $A^\star$, $B^\star$ AND $C^\star$ ARE TAKEN AS SPECIAL VALUES

| Proposed unified model | Subset $\{R_i\}$ (optimized) | Subset $\{R_j\}$ (optimized) | Subset $\{R_k\}$ (optimized) |
|-----------------------|-------------------------------|-------------------------------|-------------------------------|
| $\{A^\star\} + \{B^\star\} + \{C^\star\} = \{R_i\}$ | $\{A^\star\}$ | $\{B^\star\}$ | $\{C^\star\}$ |
| Best relay selection | $[17]-[19]$ | Arbitrary subset includes $R_i$ with best $\gamma_i$ | Best $\gamma_i$ for relay $R_i$ | $\emptyset$ |
| N-best relay selection | $[20], [21]$ | Arbitrary subset includes $R_i$ with n-best $\gamma_i$ | N-best $\gamma_i$ for relay $R_i$ | $\emptyset$ |
| Partial relays selection | $[29]-[31], [36]$ | Arbitrary subset includes $\{R_i\}$ | $\{R_i\} \subset \{R_i\}$ | $\emptyset$ |
All relays selection

\[ \{R_X\} \]

\[ \{R_X\} \]

\[ \varnothing \]

Subset selection I [34]

\[ \{R_X\} \]

\[ \{R_X\} \]

\[ \varnothing \]

Subset selection II [35]

Arbitrary subset includes \{\{R_i\}+\{R_j\}\}

\[ \{R_i\} \]

\[ \{R_j\} \]

Max-Max with buffers [37], [48]

Best \( \gamma_i \) for relay \( R_i \)

\[ \varnothing \]

Best \( \gamma_j \) for relay \( R_j \)

four sections with constant total SINR for special cases (same communications scenarios and models like RF/FSO communications in [48]-[50], when \( B'=\varnothing \), \( A' \), \( C' \neq \varnothing \) and \( \delta_{ab}=P_{ST}+\sum_{R_i+R_j}P_{R_i}\delta_{ab} \) is cons.

Firstly, in Fig.8 according to Lemma 5, when 7 selected relays are divided into 2 sections, as relay with higher SINR is corresponding to larger section, on the basis of Corollary 1, after certain relays are selected and relay numbers of sections are replaced, then we assume numbers of sections are 2:5, 3:4, 4:3, and SINR of selected relays are subjected to 2:8, 3:7, 4:6. From simulation, we find that when section numbers are excessively disparity, although SINR of selected relays are same, better OP is belong to closer number sections, and relays with different SINR in same sections also lead to OP variation apparently, hence, it is concluded that sections should be divided on the basis of SINR of selected relays and fading coefficients for each hop and relays quantities are not too great.
When relays number is 20, according to partition principle with Lemma 5 and Corollary 1, further we divide relays into 3 or 4 sections. If relays are adjusted to 3 sections, when ratios of SINR of relays are determined, we should make additive numbers of sections are as small as possible. For example, for 3 sections N(5:6:9), N(3:8:9) and N(5:7:8) are better than N(3:5:12), because 12-(3+5) > 2, and for 4 sections, (3+8)-(4+5) > (3+7)-(4+6), hence, N(2:4:6:8) and N(3:4:6:7) are lower than N(2:3:6:9) and N(3:4:5:8). In addition, allocation values of SINR for selected relays of each section should be proportional to number of corresponding sections, and lower SINR is corresponding to smaller relays numbers, larger SINR is corresponding to larger relays numbers.

![Fig.9 OP versus total SINR with 3 and 4 sections for 20 selected relays](image)

On the other hand, when $B^* \neq \emptyset$, we search for best 7 relays selection from 40 relays for unified proposed generalized optimal relays pairing algorithm, if selected relays sections are divided as (3,4,5,5,7,8,8), with the aid of results of Fig.8 and Fig.9, according to Lemma 6 and Corollary 2, $\delta_{B^*} \geq \delta_{C^*}$ and selection priority of $B^*$ and $C^*$ exceeds $A^*$, we could find that higher SINR in $B^*$ with larger relays number will be better than other cases, and larger numbers of relays in $B^*$ also have more important influence than $A^*$. It is concluded that for optimal two-hop relays communications, we should pay more attention to allocate relays with higher SINR in $B^*$, and more rational SINR
allocation should be considered for the second-hop with cooperative relays nodes.

Fig. 10 OP versus total SINR for optimal subsets pairing with 7 selected relays from 40 relays

Fig. 11 OP versus total SINR between proposed algorithm and classical relays selection schemes with 7 selected relays from 40 relays

Furthermore, we compare proposed generalized optimal two-way relays pairing algorithm with conventional selection schemes, we could find proposed algorithm has 2-6 higher orders of magnitude than other schemes, because we consider realizing optimal and multiple relays pairing more reasonably with cloud-based servers, on the basis of optimization with two-hop selection respectively. We also reveal that for relays that send signals to cloud-server in cloud-based region, the problem that only receiving data, only forwarding data (after receiving feedback signal from cloud-servers), or receiving and forwarding data can be solved in cloud-based servers, in order to
improve communication qualities.

Last, we compare computation complexity versus number of relays between proposed algorithm and relays subsets selection. According to performance analysis of computation complexity in (39) and (40), we find computation complexity is excessively lower than other relays selection scheme, and as $N$ increases, computation complexity becomes saturated.

![Fig.12 Computation complexity versus number of relays](image)

### VI. CONCLUSION

In this paper, aiming at problem that how to improve communication reliability in 5G cognitive networks, owing to classical selection algorithms are not optimum as huge differences of SINR or SNR of multiple relays in various communications scenarios. We propose generalized cloud-based region relays subsets pairing and replacement algorithm which can be converted into classical relays selection schemes, when it is set to be special values. Furthermore, we reveal relays have A, B and C characteristics in cooperative communications. In addition, simulation prove that proposed algorithm has prominent and better OP than classical selection methods, and it has lower complexity than other subsets selection method.

In general, it is concluded that proposed algorithm not only extremely releases arrangement limitations of primary users in underlay scene, but also considers improving communication
reliability with first-hop and second-hop at the same time (unlike conditionally it should be pay more attention for second-hop to reduce OP), and it reveals that for subsets selection, in order to reduce OP, higher SINR with relays nodes would be corresponding to larger SINR interval in each section, but disparity of numbers of relays in each section should be ensured as low as possible. Moreover, ideology method of multiple relays subsets pairing is proposed to solve relative cooperative communications problems in different 5G communications scenarios.

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APPENDIX

PROOF OF LEMMA 1

According to (3), for selected subsets $A+B$, SINR of $A+B$ is given by

$$\delta_{S_{ST\{|A+B\}}^{ST\{A+B\}}} = \min(P_{SF}, \frac{Q_{\text{loc}}}{h_{S_{ST\{|A+B\}}^{ST\{A+B\}}}}) \cdot \frac{|h_{S_{ST\{|A+B\}}^{ST\{A+B\}}}|^2}{N_0 + P_{TT} |h_{TT\{A+B\}}|}$$

(45)

For $R_i$, we assume threshold of SINR is $\delta_i$, hence OP of first hop is given by

$$F_{\text{1-hop}}() = Pr \left( \frac{P_{SF} |h_{X_{ST}}|^2}{N_0 + P_{TT} |h_{P_{TT}}|} \leq x, \frac{P_{SF} |h_{X_{ST}}|^2}{Q_{\text{loc}} |h_{S_{ST\{|A+B\}}^{ST\{A+B\}}}|} \leq 1 \right) + Pr \left( \frac{Q_{\text{loc}} |h_{S_{ST\{|A+B\}}^{ST\{A+B\}}}|^2}{(N_0 + P_{TT} |h_{P_{TT}}|) |h_{S_{ST\{|A+B\}}^{ST\{A+B\}}}|} \leq x, \frac{P_{SF} |h_{X_{ST}}|^2}{Q_{\text{loc}} |h_{S_{ST\{|A+B\}}^{ST\{A+B\}}}|} \geq 1 \right)$$

(46)

$M_1$ is further derived as

$$M_1 = Pr \left( \frac{P_{SF} |h_{S_{ST\{|A+B\}}^{ST\{A+B\}}}|^2}{N_0 + P_{TT} |h_{P_{TT}}|} \leq x \right) Pr \left( \frac{|h_{S_{ST\{|A+B\}}^{ST\{A+B\}}}|^2}{P_{SF}} \leq \frac{Q_{\text{loc}}}{P_{SF}} \right)$$

(47)
We assume \( h_{\text{STR}} = w_1, h_{\text{PTR}} = w_2, h_{\text{STR}2} = w_3 \), for Rayleigh fading channels, if \( \Omega = \sigma_i^2 \), PDF and CDF can be given by

\[
f_X(x) = \frac{1}{\Omega} e^{-\frac{x}{\Omega}} \quad (48)
\]

\[
F_X(x) = 1 - e^{-\frac{x}{\Omega}} \quad (49)
\]

with (48) and (49), (47) is derived as

\[
M_1 = \left( \int_{w_1}^{\infty} \int_{w_2}^{\infty} F_{w_1}(w_1) f_{w_2}(w_2) f_{w_3}(w_3) \, dw_2 \, dw_3 \right) \cdot F_{w_3}(Q_{\text{F}}) \quad (50a)
\]

\[
= \left( 1 - \exp\left( -\frac{N_0 w_1}{\sigma_{w_1}^2 P_{\text{STR}}} \right) \frac{P_{\text{STR}} \sigma_{w_1}^2}{P_{\text{STR}} \sigma_{w_1}^2 + P_{\text{PTR}} \sigma_{w_2}^2} \right) \left( 1 - \exp\left( -\frac{Q_{\text{F}}}{\sigma_{w_3}^2} \right) \right) \quad (50b)
\]

On the other hand, in (46), \( w_i \leq \frac{x w_1 (P_{\text{PTR}} w_2 + N_0)}{Q_{\text{F}}} \), then \( M_2 \) is given by

\[
M_2 = \int_{0}^{w_1} \int_{0}^{w_2} \int_{w_3}^{\infty} F_{w_1}(w_1) f_{w_2}(w_2) f_{w_3}(w_3) \, dw_2 \, dw_3 \quad (51a)
\]

\[
= \frac{1}{\sigma_{w_1}^2 \sigma_{w_2}^2} \int_{0}^{w_1} \int_{0}^{w_2} \exp\left( -\frac{w_1}{\sigma_{w_1}^2} \right) \left( \int_{0}^{w_2} \exp\left( -\frac{w_2}{\sigma_{w_2}^2} \right) \, dw_2 \right) - \int_{0}^{w_1} \exp\left( -\frac{x N_0 w_3}{\sigma_{w_3}^2 Q_{\text{F}}} \right) \cdot \exp\left( -\frac{x w_2}{\sigma_{w_3}^2 Q_{\text{F}}} \right) \cdot \exp\left( -\frac{1}{\sigma_{w_3}^2} \right) \, dw_3 \quad (51b)
\]

Simplifying integrals of formula, \( M_2 \) is derived as

\[
M_2 = \frac{1}{\sigma_{w_1}^2 \sigma_{w_2}^2} \int_{0}^{w_1} \int_{0}^{w_2} \exp\left( -\frac{w_1}{\sigma_{w_1}^2} \right) \left( \sigma_{w_1}^2 - \exp\left( -\frac{x N_0 w_3}{\sigma_{w_3}^2 Q_{\text{F}}} \right) \cdot \sigma_{w_1}^2 \sigma_{w_3}^2 Q_{\text{F}} \right) \, dw_3 \quad (52a)
\]

\[
= \exp\left( -\frac{Q_{\text{F}}}{P_{\text{STR}} \sigma_{w_1}^2} \right) - \frac{\sigma_{w_1}^2 Q_{\text{F}}}{\sigma_{w_3}^2} \int_{0}^{w_1} \int_{0}^{w_2} \frac{1}{x w_3 P_{\text{PTR}} \sigma_{w_3}^2 + \sigma_{w_3}^2 Q_{\text{F}}} \exp\left( -\frac{w_1}{\sigma_{w_1}^2} \right) - \frac{w_1 x N_0}{\sigma_{w_3}^2} \, dw_3 \quad (52b)
\]

With the aid of [53, 3.352.2] to simplify \( M_3 \), \( M_2 \) is expressed as

\[
M_2 = \exp\left( -\frac{Q_{\text{F}}}{P_{\text{STR}} \sigma_{w_1}^2} \right) + \exp\left( -\frac{\sigma_{w_1}^2 Q_{\text{F}}}{\sigma_{w_3}^2 x P_{\text{PTR}} \sigma_{w_2}^2} \right) \left( \frac{\sigma_{w_1}^2 Q_{\text{F}} + x N_0 \sigma_{w_3}^2}{\sigma_{w_3}^2} \right) E_i\left( -\frac{\sigma_{w_1}^2 Q_{\text{F}} + x N_0 \sigma_{w_3}^2}{\sigma_{w_3}^2} x P_{\text{PTR}} \right) - \frac{\sigma_{w_1}^2 Q_{\text{F}} + x N_0 \sigma_{w_3}^2}{P_{\text{STR}} \sigma_{w_1}^2} \quad (53)
\]

where \( E_i = \int_{-\infty}^{t} \exp(t) \, dt \) [53, 8.21], hence, OP of first hop is given by
PROOF OF LEMMA 2

According to (4), for selected subsets $B+C$, SINR of $B+C$ is given by

$$
\delta_{(B+C)D} = \min(P_{(B+C)|D}, \frac{Q_{R_{B+C}}}{h_{(B+C)|D}}), \quad \frac{|h_{(B+C)|D}|^2}{N_0 + P_{PT} |h_{PTD}|^2}
$$

For $R_{j}$, OP of second hop is given by

$$
F_{2-op}() = \Pr\left( \frac{P_{R_j} \left| h_{R,j} \right|^2}{N_0 + P_{PT} \left| h_{PTD} \right|^2} \leq x, \frac{P_{R_j}}{Q_{R_j}} \leq \frac{1}{ \left| h_{R,R_j} \right|^2} \right) + \Pr\left( \frac{Q_{R_j} \left| h_{R,j} \right|^2}{N_0 + P_{PT} \left| h_{PTD} \right|^2} \leq x, \frac{P_{R_j}}{Q_{R_j}} \geq \frac{1}{ \left| h_{R,R_j} \right|^2} \right)
$$

$M_4$ is given by

$$
M_4 = \Pr\left( \frac{P_{R_j} \left| h_{R,j} \right|^2}{N_0 + P_{PT} \left| h_{PTD} \right|^2} \leq x, \frac{P_{R_j}}{Q_{R_j}} \leq \frac{1}{ \left| h_{R,R_j} \right|^2} \right)
$$

We assume $\left| h_{R,j} \right|^2 = w_4, \left| h_{R,R_j} \right|^2 = w_5, \left| h_{PTD} \right|^2 = w_6$, similar to Lemma 1, $M_4$ is further derived as

$$
M_4 = F_{w_4}(\frac{Q_{R_j}}{P_{R_j}})\int F_{w_6}\left( \frac{xP_{PT}w_6 + xN_0}{P_{R_j}} \right) f_{w_5}(w_5)dw_5
$$

$$
= (1 - \exp(-\frac{Q_{R_j}}{\sigma_{u_j}^2 P_{R_j}}))(1 - \exp(-\frac{w_6}{\sigma_{w_5}^2 P_{R_j}})) \int_0^{\infty} \frac{\sigma_{w_5}^2 P_{R_j}}{\sigma_{w_5}^2 P_{R_j} + xP_{PT} \sigma_{w_6}^2} \exp(-\frac{w_6}{\sigma_{w_5}^2 P_{R_j}}) d\sigma_{w_5}
$$

On the other hand, $M_5$ is derived as

$$
M_5 = \int_0^{\infty} \int F_{w_4}\left( \frac{xP_{PT}w_6 + N_0}{Q_{R_j}} \right) f_{w_5}(w_5)dw_6dw_5
$$
\[
\int_{0}^{\infty} \frac{w_{x}}{w_{x}^{2}} \left( 1 - \exp\left( -\frac{w_{x}N_{0}}{\sigma_{m}^{2}} \right) \right) \left( 1 - \exp\left( -\frac{w_{x}x}{\sigma_{m}^{2}} \right) \right) \exp\left( -\frac{w_{x}w_{x}P_{TT}}{\sigma_{m}^{2}Q_{\beta_{j}}} \right) \, dw_{x}
\]

Simplifying integrals of formula, \( M_{5} \) is derived as

\[
M_{5} = \exp\left( -\frac{Q_{\beta_{j}}}{P_{m}^{2} \sigma_{m}^{2}} \right) \cdot \frac{\sigma_{m}^{2} Q_{\beta_{j}}}{\sigma_{m}^{2} \sigma_{m}^{2} Q_{\beta_{j}} + P_{m}^{2} \sigma_{m}^{2} w_{x}x} \cdot \exp\left( -\frac{w_{x}N_{0}}{\sigma_{m}^{2}} \right) - \frac{w_{x}x}{\sigma_{m}^{2} Q_{\beta_{j}}} \, dw_{x}
\]

With the aid of [53, 3.352.5] to simplify \( M_{6} \), \( M_{5} \) is expressed as

\[
M_{5} = \exp\left( -\frac{Q_{\beta_{j}}}{P_{m}^{2} \sigma_{m}^{2}} \right) + \frac{\sigma_{m}^{2} Q_{\beta_{j}}}{\sigma_{m}^{2} \sigma_{m}^{2} Q_{\beta_{j}} + P_{m}^{2} \sigma_{m}^{2} w_{x}x} \cdot \exp\left( -\frac{w_{x}N_{0}}{\sigma_{m}^{2}} \right) - \frac{w_{x}x}{\sigma_{m}^{2} \sigma_{m}^{2} Q_{\beta_{j}} + xN_{0} \sigma_{m}^{2}}
\]

Hence, OP of second hop is given by

\[
F_{2, \text{out}}(\cdot) = \left( 1 - \exp\left( -\frac{Q_{\beta_{j}}}{\sigma_{m}^{2} P_{m}^{2}} \right) \right) \left( 1 - \exp\left( -\frac{xN_{0}}{\sigma_{m}^{2} P_{m}^{2} x} \right) \right) \exp\left( -\frac{Q_{\beta_{j}}}{\sigma_{m}^{2} P_{m}^{2}} \right) + \frac{\sigma_{m}^{2} Q_{\beta_{j}}}{\sigma_{m}^{2} \sigma_{m}^{2} P_{m}^{2} x} \exp\left( -\frac{w_{x}N_{0}}{\sigma_{m}^{2} P_{m}^{2}} \right)
\]

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