Proyecciones Journal of Mathematics
Vol. 41, N^o 5, pp. 1239-1250, October 2022.
Universidad Católica del Norte
Antofagasta - Chile

10.22199/issn.0717-6279-5466

Decomposition dimension of corona product of some classes of graphs

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Received : May 2022. Accepted : August 2022

Abstract

For an ordered k-decomposition $\mathcal{D} = \{G_1, G_2, \ldots, G_k\}$ of a connected graph $G = (V, E)$, the $\mathcal{D}$-representation of an edge e is the k-tuple $\gamma(e/\mathcal{D}) = (d(e, G_1), d(e, G_2), \ldots, d(e, G_k))$, where $d(e, G_i)$ represents the distance from e to G_i. A decomposition $\mathcal{D}$ is resolving if every two distinct edges of G have distinct representations. The minimum k for which G has a resolving k-decomposition is its decomposition dimension $dec(G)$. In this paper, the decomposition dimension of corona product of the path P_n and cycle C_n with the complete graphs K_1 and K_2 are determined.

Key words: *Decomposition dimension, Corona product, Path, Cycle.*

Mathematical Subject Classification Codes: *05C38, 05C70*

1. Introduction

Let $G = (V, E)$ be a finite undirected connected graph without loops or multiple edges. A decomposition of a graph G is a collection of subgraphs of G, none of which have isolated vertices, whose edge sets provide a partition of $E(G)$. A decomposition of G into k subgraphs is a k-decomposition of G. A decomposition $\mathcal{D} = \{G_1, G_2, \ldots, G_k\}$ is ordered if the ordering $(G_1, G_2, \ldots, G_k)$ has been imposed on $\mathcal{D}$. If each subgraph G_i of $\mathcal{D}$ is isomorphic to a graph H, then $\mathcal{D}$ is said to be an H-decomposition of G.

For edges $e, f \in E(G)$, the distance $d(e, f)$ between e and f is the minimum non negative integer k for which there exists a sequence $e = e_0, e_1, e_2, \ldots, e_k = f$ of edges of G such that e_i and e_{i+1} are adjacent for $i = 0, 1, \ldots, k-1$. For an edge e of G and a subgraph F of G, $d(e, F) = min\{d(e, f), f \in E(F)\}$. Let $\mathcal{D} = \{G_1, G_2, \ldots, G_k\}$ be an ordered k-decomposition of G. The $\mathcal{D}$-representation of an edge e is the k-tuple $\gamma(e/\mathcal{D}) = (d(e, G_1), d(e, G_2), \ldots, d(e, G_k))$, where $d(e, G_i)$ represents the distance from e to G_i. We call $\mathcal{D}$ a resolving k-decomposition if for any pair of edges e and f, there exists some index i such that $d(e, G_i) \neq d(f, G_i)$. The minimum k for which G has a resolving k-decomposition is its decomposition dimension $dec(G)$. These concepts were introduced by Chartrand et.al in [1]. It is further studied in [2,3,8].

The concepts of resolving set and minimum resolving set have appeared in the literature previously. Slater introduced and studied these ideas with a different terminology 'locating set' in [9]. Harary and Melter [4] discovered these concepts independently. Later these concepts were rediscovered by Johnson in [5]. Chartrand et.al [1] proved that $dec(G) \geq 3$ for all connected graphs G that are not paths and for a tree T of order n and diameter d, $dec(T) \leq n - d + 1$. M. Hagita, A. Kundgen and D. B. West [3] used probabilistic methods to obtain upper bounds for decomposition dimension of complete graphs and regular graphs. H. Enomoto and T. Nakamigawa [2] established a lower bound for decomposition dimension of graphs using the maximum degree of G. They proved that for any graph G, $dec(G) \geq \lceil log_2\Delta(G) \rceil + 1$. Reji T. and Ruby R. studied about decomposition dimension of cartesian product of graphs in [6].

The corona product, $G_1 \odot G_2$ of two graphs G_1 (with n_1 vertices and m_1 edges) and G_2 (with n_2 vertices and m_2 edges) is defined as the graph obtained by taking one copy of G_1 and n_1 copies of G_2, and then joining the ith vertex of G_1 with an edge to every vertex in the ith copy of G_2.

Metric dimension and partition dimension, which distinguishes the vertices of a graph using distance, of corona product of graphs are studied in [7,10].

2. Main Results

Define $\alpha_i^+ : \mathbf{R}^n \to \mathbf{R}^n$ by $\alpha_i^+(x_1, \ldots, x_i, \ldots, x_n) = (x_1, \ldots, x_i + 1, \ldots, x_n)$ and $\alpha_i^- : \mathbf{R}^n \to \mathbf{R}^n$ by $\alpha_i^-(x_1, \ldots, x_i, \ldots, x_n) = (x_1, \ldots, x_i - 1, \ldots, x_n)$

Theorem 1. $dec(P_n \odot K_1) = \begin{cases} 2 & \text{if } n = 2 \\ 3 & \text{if } n \geq 3 \end{cases}$

Proof. **Case 1:** $n = 2$
The corona product of the path P_2 and the complete graph K_1, $P_2 \odot K_1$ is the path P_4. Hence $dec(P_2 \odot K_1) = 2$.

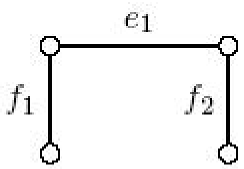

Figure 1. $P_2 \odot K_1$.

Case 2: $n \geq 3$
The corona product of the path P_n and the complete graph K_1, $P_n \odot K_1$ is also known as the n-centipede graph. Let $v_1, v_2, \ldots, v_n$ be the n vertices and $e_1, e_2, \ldots, e_{n-1}$ be the $n - 1$ edges of the path P_n. Label the edges joining the vertex v_i in P_n and K_1 as $f_i, 1 \leq i \leq n$.

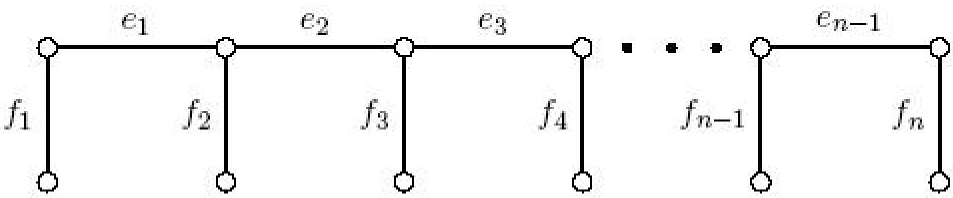

Figure 2. $P_n \odot K_1$.

Consider the decomposition $\mathcal{D} = \{G_1, G_2, G_3\}$ of $P_n \odot K_1$ where $E(G_1) = \{f_1\}$, $E(G_2) = \{f_n\}$ and $E(G_3)$ consists of all other edges of $P_n \odot K_1$. Then $\gamma(f_1/\mathcal{D}) = (0, n, 1)$, $\gamma(f_n/\mathcal{D}) = (n, 0, 1)$, $\gamma(f_i/\mathcal{D}) = (i, n+1-i, 0)$, $2 \le i \le n-1$ and $\gamma(e_i/\mathcal{D}) = (i, n-i, 0), 1 \le i \le n-1$. Thus $\mathcal{D}$ is a resolving decomposition of $P_n \odot K_1$. So $dec(P_n \odot K_1) \le 3$. Since $P_n \odot K_1$ is not a path $dec(P_n \odot K_1) \ge 3$. Hence $dec(P_n \odot K_1) = 3$. □

Theorem 2. *$dec(P_2 \odot K_2) = 3$ and $dec(P_n \odot K_2) \le 4$, if $n \ge 3$*

Proof. **Case 1:** $n = 2$
Consider the graph $P_2 \odot K_2$. Let v_1, v_2 be the vertices of the path P_2 and e_1 be the edge joining v_1 and v_2 in P_2. For $i = 1, 2$ label the edges joining the vertex v_i in P_2 and K_2 as f_i, g_i and let h_i be the edge in K_2 adjacent to the edges f_i and g_i.

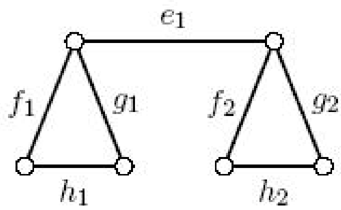

Figure 3. $P_2 \odot K_2$.

Consider the decomposition $\mathcal{D} = \{G_1, G_2, G_3\}$ of $P_2 \odot K_2$ where $E(G_1) = \{g_1\}$, $E(G_2) = \{g_2\}$ and $E(G_3)$ consists of all other edges of $P_2 \odot K_2$. Then $\gamma(g_1/\mathcal{D}) = (0, 2, 1)$, $\gamma(g_2/\mathcal{D}) = (2, 0, 1)$, $\gamma(f_1/\mathcal{D}) = (1, 2, 0)$, $\gamma(f_2/\mathcal{D}) = (2, 1, 0)$, $\gamma(h_1/\mathcal{D}) = (1, 3, 0)$, $\gamma(h_2/\mathcal{D}) = (3, 1, 0)$, $\gamma(e_1/\mathcal{D}) = (1, 1, 0)$. Thus $\mathcal{D}$ is a resolving decomposition of $P_2 \odot K_2$. So $dec(P_2 \odot K_2) \le 3$. Since $P_2 \odot K_2$ is not a path, $dec(P_2 \odot K_2) \ge 3$. Hence $dec(P_2 \odot K_2) = 3$.

Case 2: $n \ge 3$
Consider the corona product of the path P_n and the complete graph K_2, $P_n \odot K_2$. Let $v_1, v_2, \ldots, v_n$ be the n vertices and $e_1, e_2, \ldots, e_{n-1}$ be the $n-1$ edges of the path P_n. For $i = 1, 2, \ldots, n$ label the edges joining the vertex v_i in P_n and K_2 as f_i, g_i and let h_i be the edge in K_2 adjacent to the edges f_i and g_i.

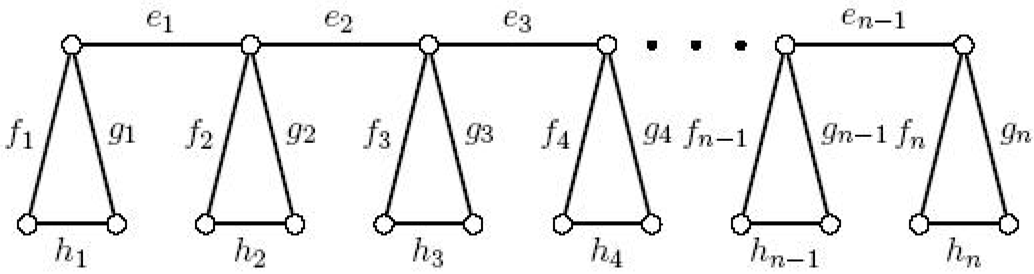

Figure 4. $P_n \odot K_2$.

Since $P_n \odot K_2$ is not a path, $dec(P_n \odot K_2) \geq 3$. Consider the decomposition $\mathcal{D} = \{G_1, G_2, G_3, G_4\}$ of $P_n \odot K_2$ where $E(G_1) = \{g_1\}$, $E(G_2) = \{g_2, g_3, \ldots, g_{n-1}\}$, $E(G_3) = \{g_n\}$ and $E(G_4)$ consists of all other edges of $P_n \odot K_2$.

Then $\gamma(g_1/\mathcal{D}) = (0, 2, n, 1)$, $\gamma(g_n/\mathcal{D}) = (n, 2, 0, 1)$, $\gamma(f_1/\mathcal{D}) = (1, 2, n, 0)$, $\gamma(f_n/\mathcal{D}) = (n, 2, 1, 0)$, $\gamma(h_1/\mathcal{D}) = (1, 3, n+1, 0)$, $\gamma(h_n/\mathcal{D}) = (n+1, 3, 1, 0)$, $\gamma(e_i/\mathcal{D}) = (i, 1, n-i, 0), 1 \leq i \leq n-1$.
For $2 \leq i \leq n-1$, $\gamma(g_i/\mathcal{D}) = (i, 0, n+1-i, 1)$, $\gamma(f_i/\mathcal{D}) = (i, 1, n+1-i, 0)$, $\gamma(h_i/\mathcal{D}) = (i+1, 1, n+2-i, 0)$. Thus $\mathcal{D}$ is a resolving decomposition of $P_n \odot K_2$. So $dec(P_n \odot K_2) \leq 4$. □

Theorem 3. $dec(C_n \odot K_1) = 3$

Proof. Consider the corona product of the cycle C_n and the complete graph K_1, $C_n \odot K_1$. Let $v_1, v_2, \ldots, v_n$ be the n vertices of the path C_n and $e_1, e_2, \ldots, e_n$ be the n edges of the cycle C_n. Label the edges joining the vertex v_i in C_n and K_1 as $f_i, 1 \leq i \leq n$.

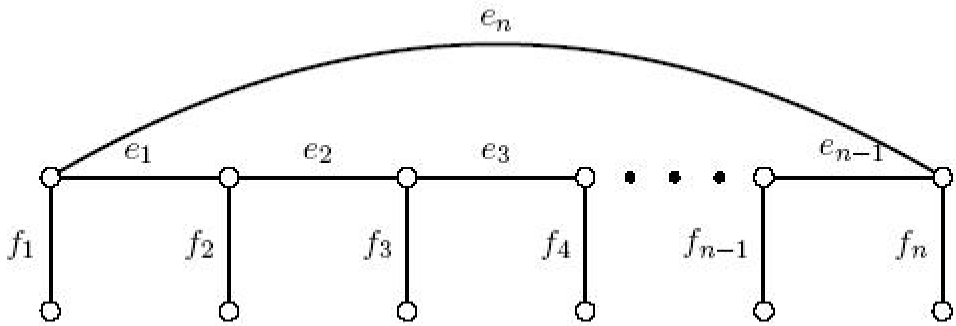

Figure 5. $C_n \odot K_1$.

Let $n \geq 3$ be any positive integer. Then $n = 3k-1$ *or* $3k$ *or* $3k+1$, where $k = 1, 2, \ldots$. Consider the decomposition $\mathcal{D} = \{G_1, G_2, G_3\}$ of $C_n \odot K_1$.

Case 1: $n = 3k - 1$

Let $E(G_1) = \{f_1, f_n, f_{n-1}, \ldots, f_{n-k+3}\}$, $E(G_2) = \{f_2, f_3, \ldots, f_{k+1}\}$ and $E(G_3)$ consists of all other edges of $C_n \odot K_1$. Then

$$\gamma(f_i/\mathcal{D}) = \begin{cases} (0,2,1) & \text{if } i = 1 \\ (i,0,1) & \text{if } 2 \leq i \leq k+1 \\ (k+1,2,0) & \text{if } i = k+2 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(f_{i-1})) & \text{if } k+3 \leq i \leq n-k+2 \\ (0,k,1) & \text{if } i = n-k+3 \\ \alpha_2^-(\gamma(f_{i-1})) & \text{if } n-k+4 \leq i \leq n \end{cases}$$

$$\gamma(e_i/\mathcal{D}) = \begin{cases} (i,1,0) & \text{if } 1 \leq i \leq k+1 \\ (k,2,0) & \text{if } i = k+2 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(e_{i-1})) & \text{if } k+3 \leq i \leq n-k+2 \\ (1,k-1,0) & \text{if } i = n-k+3 \\ \alpha_2^-(\gamma(e_{i-1})) & \text{if } n-k+4 \leq i \leq n \end{cases}$$

Case 2: $n = 3k$ *or* $3k+1$
Let $E(G_1) = \{f_1, f_n, f_{n-1}, \ldots, f_{n-k+2}\}$, $E(G_2) = \{f_2, f_3, \ldots, f_{k+1}\}$ and

$E(G_3)$ consists of all other edges of $C_n \odot K_1$.
When $n = 3k$

$$\gamma(f_i/\mathcal{D}) = \begin{cases} (0,2,1) & \text{if } i = 1 \\ (i,0,1) & \text{if } 2 \le i \le k+1 \\ (k+1,2,0) & \text{if } i = k+2 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(f_{i-1})) & \text{if } k+3 \le i \le n-k+1 \\ (0,k+1,1) & \text{if } i = n-k+2 \\ \alpha_2^-(\gamma(f_{i-1})) & \text{if } n-k+3 \le i \le n \end{cases}$$

$$\gamma(e_i/\mathcal{D}) = \begin{cases} (i,1,0) & \text{if } 1 \le i \le k+1 \\ (k,2,0) & \text{if } i = k+2 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(e_{i-1})) & \text{if } k+3 \le i \le n-k+1 \\ (1,k,0) & \text{if } i = n-k+2 \\ \alpha_2^-(\gamma(e_{i-1})) & \text{if } n-k+3 \le i \le n \end{cases}$$

When $n = 3k + 1$

$$\gamma(f_i/\mathcal{D}) = \begin{cases} (0,2,1) & \text{if } i = 1 \\ (i,0,1) & \text{if } 2 \le i \le k+1 \\ (k+2,2,0) & \text{if } i = k+2 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(f_{i-1})) & \text{if } k+3 \le i \le n-k+1 \\ (0,k+1,1) & \text{if } i = n-k+2 \\ \alpha_2^-(\gamma(f_{i-1})) & \text{if } n-k+3 \le i \le n \end{cases}$$

$$\gamma(e_i/\mathcal{D}) = \begin{cases} (i,1,0) & \text{if } 1 \le i \le k+1 \\ (k+1,2,0) & \text{if } i = k+2 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(e_{i-1})) & \text{if } k+3 \le i \le n-k \\ (1,k+1,0) & \text{if } i = n-k+1 \\ \alpha_2^-(\gamma(e_{i-1})) & \text{if } n-k+2 \le i \le n \end{cases}$$

Thus $\mathcal{D}$ is a resolving decomposition of $C_n \odot K_1$. So $dec(C_n \odot K_1) \leq 3$. Since $C_n \odot K_1$ is not a path $dec(C_n \odot K_1) \geq 3$. Hence $dec(C_n \odot K_1) = 3$. □

Theorem 4. $dec(C_n \odot K_2) \leq 4$

Proof. Consider the corona product of the cycle C_n and the complete graph K_2, $C_n \odot K_2$. Let $v_1, v_2, \ldots, v_n$ be the n vertices of the path C_n and $e_1, e_2, \ldots, e_n$ be the n edges of the cycle C_n. For $i = 1, 2, \ldots, n$ label the edges joining the vertex v_i in C_n and K_2 as f_i, g_i and let h_i be the edge in K_2 adjacent to the edges f_i and g_i.

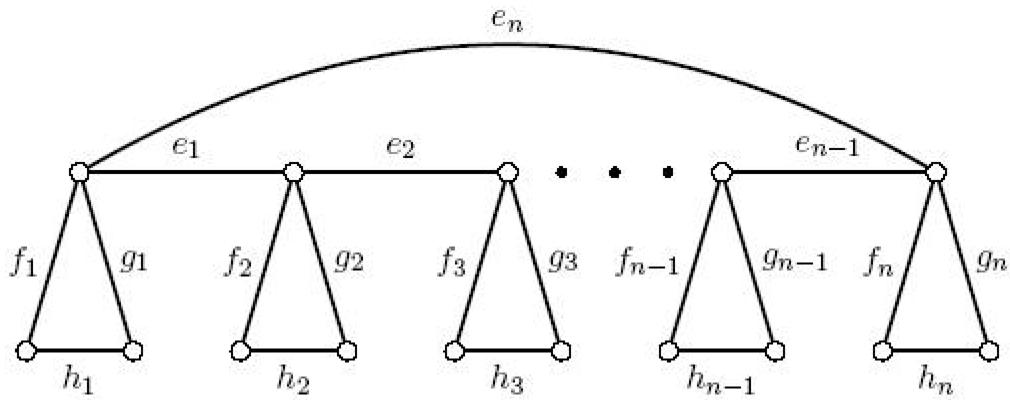

Figure 6. $C_n \odot K_2$.

Let n be any positive integer. By division algorithm there exists positive integers q, r such that $n = 3q+r$ where $r = 0$ or 1 or 2. Since $C_n \odot K_2$ is not a path, $dec(C_n \odot K_2) \geq 3$. Consider the decomposition $\mathcal{D} = \{G_1, G_2, G_3, G_4\}$ of $C_n \odot K_2$.

Case 1: $n = 3q$

Let $E(G_1) = \{g_1, g_2, \ldots, g_q\}$, $E(G_2) = \{g_{q+1}, g_{q+2}, \ldots, g_{2q}\}$, $E(G_3) = \{g_{2q+1}, g_{2q+2}, \ldots, g_n\}$ and $E(G_4)$ consists of all other edges of $C_n \odot K_2$. Then

$$\gamma(f_i/\mathcal{D}) = \begin{cases} (1, q+2-i, i+1, 0) & \text{if } 1 \le i \le q \\ (2, 1, q+1, 0) & \text{if } i = q+1 \\ (\alpha_1^+ \circ \alpha_3^-)(\gamma(f_{i-1})) & \text{if } q+2 \le i \le 2q \\ (q+1, 2, 1, 0) & \text{if } i = 2q+1 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(f_{i-1})) & \text{if } 2q+2 \le i \le n \end{cases}$$

$$\gamma(e_i/\mathcal{D}) = \begin{cases} (1, q+1-i, i+1, 0) & \text{if } 1 \le i \le q \\ (\alpha_1^+ \circ \alpha_3^-)(\gamma(e_{i-1})) & \text{if } q+1 \le i \le 2q \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(e_{i-1})) & \text{if } 2q+1 \le i \le n \end{cases}$$

$$\gamma(h_i/\mathcal{D}) = \begin{cases} (\alpha_2^+ \circ \alpha_3^+)(\gamma(f_i)) & \text{if } 1 \le i \le q \\ (\alpha_1^+ \circ \alpha_3^+)(\gamma(f_i)) & \text{if } q+1 \le i \le 2q \\ (\alpha_1^+ \circ \alpha_2^+)(\gamma(f_i)) & \text{if } 2q+1 \le i \le n \end{cases}$$

$\gamma(g_i/\mathcal{D}), 1 \le i \le n$ is obtained by replacing 1 and 0 in corresponding $\gamma(f_i/\mathcal{D})$ by 0 and 1.

Case 2: $n = 3q+1$
Let $E(G_1) = \{g_1, g_n, \ldots, g_{q+1}\}$, $E(G_2) = \{g_{q+2}, g_{q+2}, \ldots, g_{2q+1}\}$, $E(G_3) = \{g_{2q+2}, g_{2q+3}, \ldots, g_n\}$ and $E(G_4)$ consists of all other edges of $C_n \odot K_2$. Then

$$\gamma(f_i/\mathcal{D}) = \begin{cases} (1, q+3-i, i+1, 0) & \text{if } 1 \le i \le q+1 \\ (2, 1, q+1, 0) & \text{if } i = q+2 \\ (\alpha_1^+ \circ \alpha_3^-)(\gamma(f_{i-1})) & \text{if } q+3 \le i \le 2q+1 \\ (q+1, 2, 1, 0) & \text{if } i = 2q+2 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(f_{i-1})) & \text{if } 2q+3 \le i \le n \end{cases}$$

$$\gamma(e_i/\mathcal{D}) = \begin{cases} (1, q+2-i, i+1, 0) & \text{if } 1 \le i \le q \\ (1, 1, q+1, 0) & \text{if } i = q+1 \\ (\alpha_1^+ \circ \alpha_3^-)(\gamma(e_{i-1})) & \text{if } q+2 \le i \le 2q+1 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(e_{i-1})) & \text{if } 2q+2 \le i \le n \end{cases}$$

$$\gamma(h_i/\mathcal{D}) = \begin{cases} (\alpha_2^+ \circ \alpha_3^+)(\gamma(f_i)) & \text{if } 1 \le i \le q+1 \\ (\alpha_1^+ \circ \alpha_3^+)(\gamma(f_i)) & \text{if } q+2 \le i \le 2q+1 \\ (\alpha_1^+ \circ \alpha_2^+)(\gamma(f_i)) & \text{if } 2q+2 \le i \le n \end{cases}$$

$\gamma(g_i/\mathcal{D}), 1 \le i \le n$ is obtained by replacing 1 and 0 in corresponding $\gamma(f_i/\mathcal{D})$ by 0 and 1.

Case 3: $n = 3q+2$
Let $E(G_1) = \{g_1, g_n, \ldots, g_{q+1}\}$, $E(G_2) = \{g_{q+2}, g_{q+3}, \ldots, g_{2q+2}\}$, $E(G_3) = \{g_{2q+3}, g_{2q+4}, \ldots, g_n\}$ and $E(G_4)$ consists of all other edges of $C_n \odot K_2$. Then

$$\gamma(f_i/\mathcal{D}) = \begin{cases} (1, q+3-i, i+1, 0) & \text{if } 1 \le i \le q+1 \\ (2, 1, q+2, 0) & \text{if } i = q+2 \\ (\alpha_1^+ \circ \alpha_3^-)(\gamma(f_{i-1})) & \text{if } q+3 \le i \le 2q+2 \\ (q+1, 2, 1, 0) & \text{if } i = 2q+3 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(f_{i-1})) & \text{if } 2q+4 \le i \le n \end{cases}$$

$$\gamma(e_i/\mathcal{D}) = \begin{cases} (1, q+2-i, i+1, 0) & \text{if } 1 \le i \le q+1 \\ (\alpha_1^+ \circ \alpha_3^-)(\gamma(e_{i-1})) & \text{if } q+2 \le i \le 2q+1 \\ (q+1, 1, 1, 0) & \text{if } i = 2q+2 \\ (\alpha_1^- \circ \alpha_2^+)(\gamma(e_{i-1})) & \text{if } 2q+3 \le i \le n \end{cases}$$

$$\gamma(h_i/\mathcal{D}) = \begin{cases} (\alpha_2^+ \circ \alpha_3^+)(\gamma(f_i)) & \text{if } 1 \le i \le q+1 \\ (\alpha_1^+ \circ \alpha_3^+)(\gamma(f_i)) & \text{if } q+2 \le i \le 2q+2 \\ (\alpha_1^+ \circ \alpha_2^+)(\gamma(f_i)) & \text{if } 2q+3 \le i \le n \end{cases}$$

$\gamma(g_i/\mathcal{D}), 1 \le i \le n$ is obtained by replacing 1 and 0 in corresponding $\gamma(f_i/\mathcal{D})$ by 0 and 1.

Thus $\mathcal{D}$ is a resolving decomposition of $C_n \odot K_2$. So $dec(C_n \odot K_2) \le 4$. □

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