# On The Packing $k$-Coloring of Edge Corona Product 

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#### Abstract

All graph in this paper is connected and simple graph. Let $d(u, v)$ be a distance between any vertex $u$ and $v$ in graph $G=(V, E)$. A function $c: V(G) \rightarrow\{1,2, \ldots, k\}$ is called a packing $k$-coloring if every two vertices of color $i$ are at least distance $i+1 . \chi_{p}(G)$ or packing chromatic number of graph $G$ is the smallest integer of $k$ which has packing coloring. In this paper, we will study about packing $k$-coloring of graphs and determine their packing chromatic number. We have found the exact values of the packing coloring of edge corona product.


Keywords: Packing k-Coloring, Packing Chromatic Number, Edge Corona Product.

## 1. INTRODUCTION

Let G be a connected graph and k be an integer, $k \geq 1$. A packing k -coloring of a graph $G$ is a mapping $c: V(G) \rightarrow\{1,2, \ldots, k\}$ such that any two vertices of color $i$ are at distance at least $i+1$ [1]. The packing chromatic number $\chi_{p}$ of a graph $G$ is the smallest integer $k$ for which $G$ has packing k-coloring [2]. This concept firstly was introduced by Goddard, et.al, under the name broadcast coloring. Goddard, et.al [3] obtain the formula of NPcomplete for general graphs in packing coloring problem and it is NP-complete even for trees is by Fiala and Golovach [4]. The packing colorings of distance graphs has found by O. Togni [5]. The study of packing coloring some graphs in [6], [7], [8].

For illustration of packing coloring and packing chromatic number is provided in Figure 1.


Figure 1: Packing chromatic number of path, $\chi_{p}\left(P_{5}\right)=3$

Proposition. Let $H$ be a subgraph of graph $G$. Than $\chi_{p}(H) \leq \chi_{p}(G)$. [9]

Definition. Let $G_{1}$ and $G_{2}$ be two graphs on disjoint sets of $n_{1}$ and $n_{2}$ vertices, $m_{1}$ and $m_{2}$ edges, respectively. The edge corona $G_{1} \diamond G_{2}$ is defined as the graph obtained by taking one copy of $G_{1}$ and $m_{1}$ copies of $G_{2}$, and then joining two endvertices of the $i$-th edge of $G_{1}$ to every vertex in the $i$-th copy of $G_{2}$. [10]

The last, Goddard, et.al [3] have discovered the exact value of the packing chromatic number of some graph, likely path, cycle, star, bipartite graph, etc.

## 2. RESULT

Theorem 2.1 The packing chromatic number of $P_{2} \diamond P_{n}$ graph, for $n \geq 2$ is $\chi_{p}\left(P_{2} \diamond P_{n}\right)=\left\lfloor\frac{n}{2}\right\rfloor+3$.
Proof. To prove that the packing chromatic number of $P_{2} \diamond P_{n}$ graph, for $n \geq 2$ is $\chi_{p}\left(P_{2} \diamond P_{n}\right)=\left\lfloor\frac{n}{2}\right\rfloor+3$, needs to be proven using the lower bound: $\chi_{p}\left(P_{2} \diamond P_{n}\right) \geq\left\lfloor\frac{n}{2}\right\rfloor+3$ and upper bound: $\chi_{p}\left(P_{2} \diamond P_{n}\right) \leq\left\lfloor\frac{n}{2}\right\rfloor+3$.

First, we prove that the lower bound of the packing chromatic number for $P_{2} \diamond P_{n}$ graph is $\chi_{p}\left(P_{2} \diamond P_{n}\right) \geq\left\lfloor\frac{n}{2}\right\rfloor+3$. Assume that $\chi_{p}\left(P_{2} \diamond P_{n}\right)<\left\lfloor\frac{n}{2}\right\rfloor+3$. We take $\chi_{p}\left(P_{2} \diamond P_{n}\right)=\left\lfloor\frac{n}{2}\right\rfloor+2$, than we give $P_{2} \diamond P_{n}$ graph with $\left\lfloor\frac{n}{2}\right\rfloor+2$ color, so that:

- The distance of $x_{k}$ to $x_{l}$, for $1 \leq k, l \leq n$ is 2 .
- Vertex $x_{1}$ neightboring with vertex $x_{2}$ and $x_{i}$, and vice versa, than color of vertex $x_{1}$ and $x_{2}$ not equal to $x_{i}$, so $c\left(x_{1}\right) \neq c\left(x_{2}\right)$.
- In $P_{2} \diamond P_{n}$ graph, we have $2+\alpha$ color, which $\alpha$ is the color on subgraph $P_{n}$.
- In subgraph $P_{n}$ there is color 1 for n is ood and for n is even have the different color because the distance is 2, so we get that subgraph $P_{n}$ have $\left\lfloor\frac{n}{2}\right\rfloor$ color.
- We known that $\alpha=\left\lfloor\frac{n}{2}\right\rfloor$. We construct that the color of vertex with n is ood have color 1 because the distance of $x_{k}$ to $x_{l}$ is 2 .
- $\quad c\left(x_{k}\right) \neq 1$ for $k$ is even, so $c\left(x_{k}\right) \geq 2$.
- Due to distance of $x_{k}$ to $x_{l}$ is 2, than $c\left(x_{k}\right) \neq c\left(x_{l}\right)$, so that we need $\left\lfloor\frac{n}{2}\right\rfloor+1$ color.
- If we color the subgraph $P_{n}$ with $\left\lfloor\frac{n}{2}\right\rfloor$ color, than there two vertice with the same color, contradiction. So, we got that the lower bound of the packing chromatic number for $P_{2} \diamond P_{n}$ graph is $\chi_{p}\left(P_{2} \diamond P_{n}\right) \geq\left\lfloor\frac{n}{2}\right\rfloor+3$.
Furthermore, we prove that the upper bound of the packing chromatic number for $P_{2} \diamond P_{n}$ graph is $\chi_{p}\left(P_{2} \diamond P_{n}\right) \leq\left\lfloor\frac{n}{2}\right\rfloor+3$. We define $c: V(G) \rightarrow\{1,2, \ldots, k\}$ as follows:

$$
c(v)=\left\{\begin{array}{l}
1, \text { for } v=x_{j} ; j=\text { odd } \\
2+k, \text { for } v=x_{j} ; j=\text { even } ; 0 \leq k \leq n \\
c\left(x_{j}\right)+l, \text { for } v=x_{i} ; 1 \leq l \leq 2
\end{array}\right.
$$

Based on the coloring function above, we get:

- Every two vertice with color 1, have minumim distance is two from the previous vertex.
- Every two vertice with color 2, have minumim distance is three from the previous vertex.
- Every two vertice with color 3, have minumim distance is four from the previous vertex.
So that, every two vertice with color $i$, have minimum distance is $i+1$ from the previous vertex. So we get upper bound of the packing chromatic number for $P_{2} \diamond P_{n}$ graph is $\chi_{p}\left(P_{2} \diamond P_{n}\right) \leq\left\lfloor\frac{n}{2}\right\rfloor+3$.
We got that the lower bound and upper bound of the packing chromatic number for $P_{2} \diamond P_{n}$ graph is $\left\lfloor\frac{n}{2}\right\rfloor+3 \leq \chi_{p}\left(P_{2} \diamond P_{n}\right) \leq$
+3 . So it can be concluded that the packing chromatic number of $P_{2} \diamond P_{n}$ graph, for $n \geq 2$ is $\chi_{p}\left(P_{2} \diamond P_{n}\right)=\left\lfloor\frac{n}{2}\right\rfloor+3$.

Theorem 2.2 The packing chromatic number of $P_{2} \diamond S_{n}$ graph, for $n \geq 2$ is $\chi_{p}\left(P_{2} \diamond S_{n}\right)=4$.
Proof. To prove that the packing chromatic number of $P_{2} \diamond S_{n}$ graph, for $n \geq 2$ is $\chi_{p}\left(P_{2} \diamond S_{n}\right)=4$, needs to be proven using the lower bound: $\chi_{p}\left(P_{2} \diamond S_{n}\right) \geq 4$ and upper bound: $\chi_{p}\left(P_{2} \diamond S_{n}\right) \leq 4$.
First, we prove that the lower bound of the packing chromatic number for $P_{2} \diamond S_{n}$ graph is $\chi_{p}\left(P_{2} \diamond S_{n}\right) \geq 4$. Assume that $\chi_{p}\left(P_{2} \diamond S_{n}\right)<4$. We take $\chi_{p}\left(P_{2} \diamond S_{n}\right)=3$, than we give $P_{2} \diamond S_{n}$ graph with 3 color, so that:

- The distance of $y_{k}$ to $x_{l}$, for $1 \leq l \leq 2$ is 1 .
- Vertex $y_{j}$ neightboring with vertex $y$ and $x_{i}$, and vice versa, than color of vertex $y$ and $x_{i}$ not equal to $y_{j}$, so $c(y) \neq c\left(x_{i}\right)$.
- In $P_{2} \diamond S_{n}$ graph, we have 3 color, which there is 2 color on subgraph $S_{n}$.
- In subgraph $S_{n}$ there is color 1 for $y_{j} ; 1 \leq j \leq n$ and for vertex $y$ have the different color because the distance is 1 , so we get that subgraph $S_{n}$ have 2 color.
- We known that in subgraph $S_{n}$ have 2 color. We construct that the color of vertex $x_{i} \neq 1$ because the distance of $y_{j}$ to $x_{i}$ is 1 .
- $c\left(x_{i}\right)$ for $1 \leq i \leq 2$ cann't have color 2 , so $c\left(x_{i}\right) \geq 3$.
- The distance of $x_{k}$ to $x_{l}$ is 1 , than $c\left(x_{k}\right) \neq c\left(x_{l}\right)$, so we need 4 color.
- If we color the $P_{2} \diamond S_{n}$ graph with 3 color, than there two vertice with the same color, contradiction. So, we got that the lower bound of the packing chromatic number for $P_{2} \diamond S_{n}$ graph is $\chi_{p}\left(P_{2} \diamond S_{n}\right) \geq 4$.
Furthermore, we prove that the upper bound of the packing chromatic number for $P_{2} \diamond S_{n}$ graph is $\chi_{p}\left(P_{2} \diamond S_{n}\right) \leq 4$. We define $c: V(G) \rightarrow\{1,2, \ldots, k\}$ as follows:

$$
c(v)=\left\{\begin{array}{l}
1, \text { for } v=y_{j} ; 1 \leq j \leq n \\
2, \text { for } v=y \\
2+k, \text { for } v=x_{i} ; 1 \leq i, k \leq 2
\end{array}\right.
$$

Based on the coloring function above, we get:

- Every two vertice with color 1, have minumim distance is two from the previous vertex.
- Every two vertice with color 2, have minumim distance is three from the previous vertex.
- Every two vertice with color 3, have minumim distance is four from the previous vertex.
So that, every two vertice with color $i$, have minimum distance is $i+1$ from the previous vertex. So we get upper bound of the packing chromatic number for $P_{2} \diamond S_{n}$ graph is $\chi_{p}\left(P_{2} \diamond S_{n}\right) \leq 4$.
We got that the lower bound and upper bound of the packing chromatic number for $P_{2} \diamond S_{n}$ graph is $4 \leq \chi_{p}\left(P_{2} \diamond S_{n}\right) \leq 4$. So it can be concluded that the packing chromatic number of $P_{2} \diamond S_{n}$ graph, for $n \geq 2$ is $\chi_{p}\left(P_{2} \diamond S_{n}\right)=4$.

Theorem 2.3 The packing chromatic number of $P_{2} \diamond C_{n}$ graph, for $n \geq 3$ is $\chi_{p}\left(P_{2} \diamond C_{n}\right)=\left\{\begin{array}{l}5, \text { for } n=0(\bmod ) 4 \\ 6, \text { for } n=1,2,3(\bmod ) 4\end{array}\right.$.
Proof. There are two cases in the packing chromatic number of $P_{2} \diamond C_{n}$ graph, for $n \geq 3$ namely for $n=0(\bmod ) 4$ and for $n=1,2,3(\bmod ) 4$. The explanation of the two cases as follows.
Case 1: for $n=0(\bmod ) 4$
To prove that the packing chromatic number of $P_{2} \diamond C_{n}$ graph, for $n \geq 3$ is $\chi_{p}\left(P_{2} \diamond C_{n}\right)=5$, needs to be proven using the lower bound: $\chi_{p}\left(P_{2} \diamond C_{n}\right) \geq 5$ and upper bound: $\chi_{p}\left(P_{2} \diamond C_{n}\right) \leq 5$.
First, we prove that the lower bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $\chi_{p}\left(P_{2} \diamond C_{n}\right) \geq 5$. Assume that $\chi_{p}\left(P_{2} \diamond C_{n}\right)<5$. We take $\chi_{p}\left(P_{2} \diamond C_{n}\right)=4$, than we give $P_{2} \diamond P_{n}$ graph with 4 color, so that:

- The distance of $y_{k}$ to $y_{l}$, for $1 \leq k, l \leq n$ is 2 .
- Vertex $y_{1}$ neightboring with vertex $y_{2}$ and $x_{i}$, and vice versa, than color of vertex $y_{1}$ and $y_{2}$ not equal to $x_{i}$, so $c\left(y_{1}\right) \neq c\left(y_{2}\right)$.
- In $P_{2} \diamond P_{n}$ graph, we have 4 color, which there is 3 color on subgraph $C_{n}$.
- In subgraph $C_{n}$ there is color 1 for $n=1(\bmod ) 2$, color 2 for $n=2(\bmod ) 4$ because the distance is 3 , and color 3 for $n=4(\bmod ) 4$ because the distance is 4 , so we get that subgraph $C_{n}$ have 3 color.
- We known that in subgraph $C_{n}$ have 3 color. We construct that the color of vertex $x_{i} \neq 1$ because the distance of $y_{j}$ to $x_{i}$ is 1 .
- $c\left(x_{i}\right)$ for $1 \leq i \leq 2$ cann't have color 2 because the distance of $y_{j}$ to $x_{i}$ is 1 , so $c\left(x_{i}\right) \geq 3$.
- $c\left(x_{i}\right)$ for $1 \leq i \leq 2$ cann't have color 3 too, because the distance of $y_{j}$ to $x_{i}$ is 1 , so $c\left(x_{i}\right) \geq 4$.
- The distance of $x_{k}$ to $x_{l}$ is 1 , than $c\left(x_{k}\right) \neq c\left(x_{l}\right)$, so we need 5 color.
- If we color the $P_{2} \diamond C_{n}$ graph with 4 color, than there two vertice with the same color, contradiction. So, we got that the lower bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $\chi_{p}\left(P_{2} \diamond C_{n}\right) \geq 5$.
Furthermore, we prove that the upper bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $\chi_{p}\left(P_{2} \diamond C_{n}\right) \leq 5$. We define $c: V(G) \rightarrow\{1,2, \ldots, k\}$ as follows:

$$
c(v)=\left\{\begin{array}{l}
1, \text { for } v=y_{j} ; j=1(\bmod ) 2 ; 1 \leq j \leq n \\
2, \text { for } v=y_{j} ; j=2(\bmod ) 4 ; 1 \leq j \leq n \\
3, \text { for } v=y_{j} ; j=4(\bmod ) 4 ; 1 \leq j \leq n \\
c\left(y_{j}\right)+k, \text { for } v=x_{i} ; 1 \leq i, k \leq 2
\end{array}\right.
$$

Based on the coloring function above, we get:

- Every two vertice with color 1, have minumim distance is two from the previous vertex.
- Every two vertice with color 2, have minumim distance is three from the previous vertex.
- Every two vertice with color 3, have minumim distance is four from the previous vertex.
So that, every two vertice with color $i$, have minimum distance is $i+1$ from the previous vertex. So we get upper bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $\chi_{p}\left(P_{2} \diamond C_{n}\right) \leq 5$.
We got that the lower bound and upper bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $5 \leq \chi_{p}\left(P_{2} \diamond C_{n}\right) \leq 5$. So it can be concluded that the packing chromatic number of $P_{2} \diamond C_{n}$ graph, for $n \geq 3$ is $\chi_{p}\left(P_{2} \diamond C_{n}\right)=5$, for $n=0(\bmod ) 4$

Case 2: for $n=1,2,3(\bmod ) 4$
To prove that the packing chromatic number of $P_{2} \diamond C_{n}$ graph, for $n \geq 3$ is $\chi_{p}\left(P_{2} \diamond C_{n}\right)=6$, needs to be proven using the lower bound: $\chi_{p}\left(P_{2} \diamond C_{n}\right) \geq 6$ and upper bound: $\chi_{p}\left(P_{2} \diamond C_{n}\right) \leq 6$.
First, we prove that the lower bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $\chi_{p}\left(P_{2} \diamond C_{n}\right) \geq 6$. Assume that $\chi_{p}\left(P_{2} \diamond P_{n}\right)<6$. We take $\chi_{p}\left(P_{2} \diamond C_{n}\right)=5$, than we give $P_{2} \diamond C_{n}$ graph with 5 color, so that:

- The distance of $y_{k}$ to $y_{l}$, for $1 \leq k, l \leq n$ is 2 .
- Vertex $y_{1}$ neightboring with vertex $y_{2}$ and $x_{i}$, and vice versa, than color of vertex $y_{1}$ and $y_{2}$ not equal to $x_{i}$, so $c\left(y_{1}\right) \neq c\left(y_{2}\right)$.
- In $P_{2} \diamond P_{n}$ graph, we have 5 color, which there is 4 color on subgraph $C_{n}$.
- In subgraph $C_{n}$ there is color 1 for $n=1(\bmod ) 2$, color 2 for $n=2(\bmod ) 4$ because the distance is 3 , color 3 for $n=4(\bmod ) 4$ because the distance is 4 , and color 4 for $n$ is otherwise, so we get that subgraph $C_{n}$ have 4 color.
- We known that in subgraph $C_{n}$ have 4 color. We construct that the color of vertex $x_{i} \neq 1$ because the distance of $y_{j}$ to $x_{i}$ is 1 .
- $c\left(x_{i}\right)$ for $1 \leq i \leq 2$ cann't have color 2 because the distance of $y_{j}$ to $x_{i}$ is 1 , so $c\left(x_{i}\right) \geq 3$.
- $c\left(x_{i}\right)$ for $1 \leq i \leq 2$ cann't have color 3 too, because the distance of $y_{j}$ to $x_{i}$ is 1 , so $c\left(x_{i}\right) \geq 4$.
- $c\left(x_{i}\right)$ for $1 \leq i \leq 2$ cann't have color 4 too, because the distance of $y_{j}$ to $x_{i}$ is 1 , so $c\left(x_{i}\right) \geq 5$.
- The distance of $x_{k}$ to $x_{l}$ is 1 , than $c\left(x_{k}\right) \neq c\left(x_{l}\right)$, so we need 6 color.
- If we color the $P_{2} \diamond C_{n}$ graph with 5 color, than there two vertice with the same color, contradiction. So, we got that the lower bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $\chi_{p}\left(P_{2} \diamond C_{n}\right) \geq 6$.
Furthermore, we prove that the upper bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $\chi_{p}\left(P_{2} \diamond C_{n}\right) \leq 6$. We define $c: V(G) \rightarrow\{1,2, \ldots, k\}$ as follows:

$$
c(v)=\left\{\begin{array}{l}
1, \text { for } v=y_{j} ; j=1(\bmod ) 2 ; 1 \leq j \leq n \\
2, \text { for } v=y_{j} ; j=2(\bmod ) 4 ; 1 \leq j \leq n \\
3, \text { for } v=y_{j} ; j=4(\bmod ) 4 ; 1 \leq j \leq n \\
4, \text { for } v=y_{j} ; j=n ; 1 \leq j \leq n \\
c\left(y_{j}\right)+k, \text { for } v=x_{i} ; 1 \leq i, k \leq 2
\end{array}\right.
$$

Based on the coloring function above, we get:

- Every two vertice with color 1, have minumim distance is two from the previous vertex.
- Every two vertice with color 2, have minumim distance is three from the previous vertex.
- Every two vertice with color 3, have minumim distance is four from the previous vertex.
So that, every two vertice with color $i$, have minimum distance is $i+1$ from the previous vertex. So we get upper bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $\chi_{p}\left(P_{2} \diamond C_{n}\right) \leq 6$.
We got that the lower bound and upper bound of the packing chromatic number for $P_{2} \diamond C_{n}$ graph is $6 \leq \chi_{p}\left(P_{2} \diamond C_{n}\right) \leq 6$. So it can be concluded that the packing chromatic number of $P_{2} \diamond C_{n} \quad$ graph, for $n \geq 3$ is $\chi_{p}\left(P_{2} \diamond C_{n}\right)=6$, for $n=1,2,3(\bmod ) 4$.

So we can conclede that in Theorem 2.3 there are two cases namely for $n=0(\bmod ) 4$ and for $n=1,2,3(\bmod ) 4$ which have been proven right or true from the expanation above.

## 3. CONCLUSION

In this paper, we have studied packing coloring of edge corona product. We have concluded the exact value of the packing chromatic number of $P_{2} \diamond P_{n}$ graph, namely $\chi_{p}\left(P_{2} \diamond P_{n}\right)=\left\lfloor\frac{n}{2}\right\rfloor+3$, the packing chromatic number of $P_{2} \diamond S_{n}$ graph, namely $\chi_{p}\left(P_{2} \diamond S_{n}\right)=4$, and the packing chromatic number of $P_{2} \diamond C_{n}$ graph, namely for $n=0(\bmod ) 4$ is $\chi_{p}\left(P_{2} \diamond C_{n}\right)=5$ and for $n=1,2,3(\bmod ) 4$ is $\chi_{p}\left(P_{2} \diamond C_{n}\right)=6$ . Hence the following problem arises naturally.

## 4. ACKNOWLEDGEMENT

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