ON THE LOCATING CHROMATIC NUMBER OF DISJOINT UNION OF BUCKMINSTERFULLERENE GRAPHS

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ABSTRACT

Let \( G = (V, E) \) be a connected non-trivial graph. Let \( c \) be a proper vertex-coloring using \( k \) colors, namely \( 1, 2, \ldots, k \). Let \( \Pi = \{S_1, S_2, \ldots, S_k\} \) be a partition of \( V(G) \) induced by \( c \), where \( S_i \) is the color class that receives the color \( i \). The color code, denoted by \( c_\Pi(v) \), is defined as
\[
c_\Pi(v) = (d(v, S_1), d(v, S_2), \ldots, d(v, S_k)),
\]
where \( d(v, S_i) = \min\{d(v, x) \mid x \in S_i\} \) for \( 1 \leq i \leq k \), and \( d(v, x) \) is the distance between two vertices \( v \) and \( x \) in \( G \). If all vertices in \( V(G) \) have different color codes, then \( c \) is called as the locating-chromatic \( k \)-coloring of \( G \). The locating-chromatic number of \( G \), denoted by \( \chi_L(G) \), is the minimum \( k \) such that \( G \) has a locating coloring. Let \( B_{60} \) be the Buckminsterfullerene graph on 60 vertices. Buckminsterfullerene graph is a 3-connected planar graph and a member of the fullerene graphs, representing fullerene molecules in chemistry. In this paper, we determine the locating chromatic number of the disjoint union of Buckminsterfullerene graphs, denoted by \( H = \bigcup_{s=1}^{5} B_{60}^{(s)} \).

Keywords:
Locating-Chromatic Number; Buckminsterfullerene Graph; Disjoint Union of Buckminsterfullerene Graphs

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1. INTRODUCTION

Many papers have discussed the locating-chromatic number since Chartrand et al. [1] introduced the concept in 2002. The locating-chromatic number of a graph is a newly interesting topic to study because there is no general theorem for determining the locating-chromatic number of any graph. All graphs considered in this paper are finite, undirected, and simple. Let $G = (V, E)$ be a connected graph. Let $c$ be a proper coloring using $k$ colors, namely $1, 2, \cdots, k$. Let $\Pi = \{S_1, S_2, \cdots, S_k\}$ be a partition of $V(G)$ induced by $c$, where $S_i$ is the color class that receives the color $i$. The color code, denoted by $c_\Pi(v)$, is defined as
\[
c_\Pi(v) = (d(v, S_1), d(v, S_2), \ldots, d(v, S_k)),
\]
where $d(v, S_i) = \min \{d(v, x) | x \in S_i\}$ for $1 \leq i \leq k$, and $d(v, x)$ is the distance between two vertices $v$ and $x$ in $G$. If all vertices in $V(G)$ have different color codes, then $c$ is called as the locating-chromatic $k$-coloring of $G$. The locating-chromatic number of $G$, denoted by $\chi_L(G)$, is the minimum $k$ such that $G$ has a locating coloring. The dominant vertex is the vertex $v$ such that $d(v, S_1) = 0$ if $v \in S_1$, and $d(v, S_i) = 1$ if $v \notin S_i$. Other notations and definitions in graph theory are taken from Diestel [2].

Some interesting results are obtained to determine the locating-chromatic number of some connected graphs. The results are focused on certain families of graphs. Chartrand et al. [1] determined all graphs of order $n$ with locating-chromatic number $n$, namely, a complete multipartite graph of $n$ vertices. Moreover, Chartrand et al. [3] constructed trees on $n$ vertices, $n \geq 5$, with locating-chromatic numbers varying from 3 to $n$, except for $n - 1$. In [4], Baskoro and Asmiati characterized all trees with locating-chromatic number 3.

Next, Wellyyanti et al. [5] determined the locating-chromatic number for complete $n$-ary trees. Moreover, Syofyan et al. [6] characterized all trees of order with locating-chromatic number $n - 1$, for any integers $n$ and $t$, where $n > t + 3$ and $2 \leq t \leq \frac{n}{2}$. In [7], Asmiati et al. determined the locating-chromatic number of the amalgamation of stars. In [8], Asmiati et al. obtained the locating-chromatic number for the amalgamation of stars linked by one path. Asmiati et al. [9] determined the characterization of some Petersen graphs having locating-chromatic numbers four or five. Next, Asmiati et al. [10] obtained the locating-chromatic number for certain barbell graphs.

Wellyyanti et al. [11] generalized the concept of the locating-chromatic number such that it can be applied to disconnected graphs. The locating-chromatic number of a disconnected graph $H$, denoted by $\chi_L(H)$, is the smallest $k$ such that $H$ admits a locating coloring with $k$ colors. If no integer satisfies the above conditions, then the locating-chromatic number of $H$ is defined as $\chi_L(H) = \infty$. Some recent results are the locating-chromatic number of a graph with two components [12], two homogeneous components [13], and disconnected graphs with path, cycle, and star or double stars as its components [14]. Recently, Zikra et al. [15] determined the locating-chromatic number of disjoint unions of fan graphs.

In [16], Andova et al. discussed the fullerene graphs, the graph representation of fullerene molecules, where fullerenes are polyhedral molecules in chemistry made entirely of carbon atoms. They also determined that the fullerene graphs are 3-connected planar graphs with precisely 12 pentagonal faces, while all other faces are hexagons. Akhter et al. [17] obtained the metric dimension of some $(3, 6) - $fullerene and $(4, 6) - $fullerene graphs, where $(k, 6) - $fullerene graph is fullerene graph with all faces on $k$ and six vertices, for $k = 3, 4, 5$. Next, Mehreen et al. [18] obtained the partition dimension of $(3, 6) - $fullerene graphs and gave some conjecture related to the structure of $(5, 6) - $fullerene graphs.

The most symmetric fullerene graph is the Buckminsterfullerene, $B_{60}$, discovered by Kroto et al. [19]. This $(5, 6) - $fullerene graph comprises 60 carbon atoms and is named after Buckminster Fuller, whose geodetic dome resembled the structure of the molecules. Putri et al. [20] determined the metric dimension of Buckminsterfullerene $B_{60}$. Moreover, in [21], Mardimar et al. obtained the locating chromatic number of the Buckminsterfullerene graph $B_{60}$. The recent result is the locating chromatic number of the Buckminsterfullerene-type graph $B_{60}(1, t)$ for $1 \leq t \leq 5$ by Putri et al. [22]. Motivated by the result of [21] and of [22], we construct a new graph, namely the disjoint union of Buckminsterfullerene graphs, denoted by $H = \bigcup_{t=1}^{5} B_{60}(5)$, and determine its locating-chromatic number.
2. RESEARCH METHODS

Let \( G \) be a non-trivial connected graph. The upper bound of the locating chromatic number of \( G \) is obtained by constructing a partition \( \Pi = \{S_1, S_2, \ldots, S_k\} \) for some positive integer \( k \) such that every two vertices in \( G \) have different color codes, denoted by \( \chi_L(G) \leq k \). The lower bound of \( \chi_L(G) \) is determined by showing that for every possibility of \( \Pi' \) with \( |\Pi'| < k \), there are at least two vertices with the same color codes, denoted by \( \chi_L(G) \geq k \). The proof for disconnected graph \( H \) is similar. If no integer \( k \) satisfies the above conditions, then the locating-chromatic number of \( H \) is defined as \( \chi'_L(H) = \infty \).

Chartrand et al. [1] gave some characterization for the locating-chromatic coloring of a graph in Theorem 1. This theorem showed some restrictions in the construction of vertex coloring of a graph.

**Theorem 1.** [1] Let \( G \) be a connected graph, and \( c \) be a locating-chromatic coloring of \( G \). If \( v, w \in V(G) \) and \( v \neq w \) such that \( d(v, x) = d(w, x) \) for all \( x \in V(G) \setminus \{v, w\} \), then \( c(v) \neq c(w) \). In particular, if \( v \) and \( w \) are two non-adjacent vertices of \( G \) such that the neighborhood of \( v \) is equal to that of \( w \), then \( c(v) \neq c(w) \).

Welyyanti et al. [11] gave the upper and lower bounds of the locating-chromatic number for the disjoint union of arbitrarily connected graphs.

**Theorem 2.** [11] For every \( i \), let \( G_i \) be the connected graph, and let \( H = \bigcup_{i=1}^{m} G_i \). If \( \chi'_L(G) < \infty \) then
\[
\max\{\chi_L(G_i)|1 \leq i \leq m\} \leq \chi'_L(H) \leq \min\{|V(G_i)| \mid 1 \leq i \leq m\}.
\]

3. RESULTS AND DISCUSSION

In this section, we will discuss about the locating-chromatic number of the disjoint union of Buckminsterfullerene graphs, denoted by \( H = \bigcup_{s=1}^{5} B_{60}^{(5)} \). The vertex-set and edge-set of the Buckminsterfullerene graph \( B_{60} \) are given by Putri et al. [20] as follows.

\[
\begin{align*}
V(B_{60}) &= \{v_i, z_i|1 \leq i \leq 5\} \cup \{w_j, y_j|1 \leq j \leq 15\} \cup \{x_k|1 \leq k \leq 20\}, \\
E(B_{60}) &= \{v_i v_{i+1}, z_i z_{i+1}|1 \leq i \leq 4\} \cup \{w_m w_{m+1}, y_m y_{m+1}|1 \leq m \leq 14\} \\
&\quad \bigcup \{x_n x_{n+1}|1 \leq n \leq 19\} \cup \{w_{3l} x_{4l+1}, x_{4l+1} y_{3l+1}, y_{3l+1} z_{l+1}|1 \leq l \leq 4\} \\
&\quad \bigcup \{v_i w_{3l-2}, w_{3l-1} x_{4l-2}, x_{4l-2} y_{3l-1}|1 \leq i \leq 5\} \\
&\quad \bigcup \{w_{15} x_{15}, x_{20} y_{15}, y_{15} z_{15}, v_1 v_5, z_1 z_5, w_1 w_{15}, y_1 y_{15}, x_1 x_{20}\}.
\end{align*}
\]

Mardimar et al. [21] determined the locating-chromatic number for Buckminsterfullerene graph \( B_{60} \) as follows.

**Theorem 3.** [21] Let \( B_{60} \) be the Buckminsterfullerene graph. Then \( \chi_L(B_{60}) = 5 \).

**Proof.** The sketch of proof is as follows. Because \( B_{60} \) is a 3-regular graph, then it is clear that \( \chi_L(B_{60}) \geq 4 \). Next, assume that \( \chi_L(B_{60}) = 4 \). Because every vertex has degree 3, then every vertex in \( B_{60} \) is the dominant vertex. Therefore, we have four ways to color each vertex and its neighbors. Because \( |V(B_{60})| = 60 \), then at least two dominant vertices are in the same color class. Thus, \( \chi_L(B_{60}) \geq 5 \).

Next, by defining \( c: V(B_{60}) \to \{1, 2, 3, 4, 5\} \) as follows:
\[
c(v) = \begin{cases} 
1, v = z_1, y_1, y_3, y_5, y_9, y_{12}, y_{14}, x_1, x_4, x_5, x_6, x_8, x_{12}, x_{16}, x_{18}, w_6, w_9, w_{12}, \\
2, v = z_3, z_5, y_2, y_4, y_7, y_{10}, y_{13}, y_{15}, x_2, x_{11}, x_{15}, x_{17}, x_{19}, w_4, w_7, w_9, w_{11}, w_{13}, w_{15}, w_4, \\
3, v = x_9, x_{14}, w_3, w_{10}, v_1, \\
4, v = w_3, v_3, \\
5, v = z_2, z_4, y_6, y_{11}, x_3, x_5, x_7, x_{10}, x_{13}, x_{20}, w_2, w_5, w_{14}, v_2, v_5,
\end{cases}
\]

it can be easily shown that for \( \Pi = \{S_1, S_2, S_3, S_4, S_5\} \), where
For the corresponding vertices (Theorem 4) \( V(H) = \{v_{s,j},v_{s,j}|1 \leq i \leq 5\} \cup \{w_{s,j},y_{s,j}|1 \leq j \leq 15\} \cup \{x_{s,k}|1 \leq k \leq 20\} \),

\[ (4) \]

\[ E(H) = \{v_{s,1}v_{s,1},z_{s,1}z_{s,1}|1 \leq l \leq 4\} \cup \{w_{s,m}w_{s,m+1},y_{s,m}y_{s,m+1}|1 \leq m \leq 14\} \cup \{x_{s,n}x_{s,n}|1 \leq n \leq 19\} \cup \{w_{s,1}w_{s,1},w_{s,1}y_{s,1},w_{s,1}z_{s,1},w_{s,1}z_{s,1}|1 \leq i \leq 5\} \cup \{v_{s,1}w_{s,1},w_{s,1}z_{s,1},w_{s,1}z_{s,1}|1 \leq i \leq 5\} \cup \{w_{s,1}w_{s,1},w_{s,1}y_{s,1},w_{s,1}z_{s,1},w_{s,1}z_{s,1}|1 \leq i \leq 5\} \]

In Theorem 4, we determine the chromatic location number of the disjoint union of Buckminsterfullerene graphs \( H = \bigcup_{s=1}^{5} B_{60}^{(s)} \).

**Theorem 4.** Let \( H = \bigcup_{s=1}^{5} B_{60}^{(s)} \) as the disjoint union of Buckminsterfullerene graphs. Then \( \chi'_L(H) = 5 \).

**Proof.** Let \( H = \bigcup_{s=1}^{5} B_{60}^{(s)} \) be the disjoint union of Buckminsterfullerene graphs. Since \( \chi'_L(B_{60}) = 5 \) (Theorem 3), then we have that \( \chi'_L(G) = \max(\chi'_L(G))1 \leq i \leq m = 5 \), from Theorem 2.

Let \( c_1(a_{1,i}) = q \) for \( a_{1,i} \in V(B_{60}^{(1)}) \) for \( 1 \leq q \leq 5 \) and \( 1 \leq i \leq 60 \), following the 5-coloring in eq. (3).

For the corresponding vertices \( a_{p,i} \in B_{60}^{(p)} \), \( 2 \leq p \leq 5 \), define the 5-coloring as follows. In constructing this coloring, we use Theorem 1 as the restriction.

\[ c_1(a_{2,i}) = (q + 1) \mod 5, \text{ for } a_{2,i} \in B_{60}^{(2)} \]
\[ c_1(a_{3,i}) = (q + 2) \mod 5, \text{ for } a_{3,i} \in B_{60}^{(3)} \]
\[ c_1(a_{4,i}) = (q + 3) \mod 5, \text{ for } a_{4,i} \in B_{60}^{(4)} \]
\[ c_1(a_{5,i}) = (q + 4) \mod 5, \text{ for } a_{5,i} \in B_{60}^{(5)} \]

By this coloring, we define \( \Pi = \{S_1,S_2,S_3,S_4,S_5\} \), where:

\[ S_1 = \{z_{1,1},y_{1,1},y_{1,1},y_{1,5},y_{1,10},y_{1,12},y_{1,14},x_{1,1},x_{1,14},x_{1,6},x_{1,8},x_{1,12},x_{1,16},x_{1,18},w_{1,6},w_{1,8},w_{1,12}\} \cup \{z_{2,2},z_{2,4},z_{2,6},y_{2,2},y_{2,11},x_{2,3},x_{2,5},x_{2,7},x_{2,10},x_{2,13},x_{2,20},w_{2,2},w_{2,5},w_{2,14},v_{2,2},v_{2,5}\} \cup \{w_{1,1},v_{3,3}\} \cup \{x_{4,9},x_{4,14},w_{4,3},w_{4,10},v_{4,1}\} \cup \{z_{5,3},z_{5,5},z_{5,2},y_{5,4},y_{5,7},y_{5,10},y_{5,13},y_{5,15},x_{5,2},x_{5,11},x_{5,15},x_{5,17},x_{5,19}\} \cup \{w_{5,4},w_{5,7},w_{5,9},w_{5,10},w_{5,13},w_{5,15},v_{5,4}\} \]

\[ S_2 = \{z_{2,1},z_{1,5},y_{1,2},y_{1,4},y_{1,7},y_{1,10},y_{1,13},y_{1,15},x_{1,2},x_{1,11},x_{1,15},x_{1,17},x_{1,19}\} \cup \{w_{1,4},w_{1,7},w_{1,9},w_{1,11},w_{1,13},x_{1,15},v_{1,4}\} \cup \{z_{2,1},y_{2,1},y_{2,3},y_{2,5},y_{2,9},y_{2,12},y_{2,14},x_{2,1},x_{2,4},x_{2,6},x_{2,8},x_{2,12},x_{2,16},x_{2,18},w_{2,6},w_{2,8},w_{2,12}\} \cup \{z_{3,2},z_{3,4},z_{3,6},y_{3,8},y_{3,11},x_{3,3},x_{3,5},x_{3,7},x_{3,10},x_{3,13},x_{3,20},w_{3,3},w_{3,14},v_{3,2},v_{3,5}\} \cup \{w_{4,1},v_{4,3}\} \cup \{x_{5,9},x_{5,14},w_{5,3},w_{5,10},w_{5,15}\} \]

\[ S_3 = \{z_{1,9},x_{1,14},w_{1,3},w_{1,10},v_{1,1}\} \cup \{z_{2,3},z_{2,5},y_{2,2},y_{2,4},y_{2,7},y_{2,10},y_{2,13},y_{2,15},x_{2,2},x_{2,11},x_{2,15},x_{2,17},x_{2,19}\} \cup \{w_{2,4},w_{2,7},w_{2,9},w_{2,11},w_{2,13},w_{2,15},v_{2,4}\} \cup \{z_{3,1},y_{3,1},y_{3,3},y_{3,5},y_{3,9},y_{3,12},y_{3,14},x_{3,1},x_{3,4},x_{3,6},x_{3,8},x_{3,12},x_{3,16},x_{3,18},w_{3,6},w_{3,8},w_{3,12}\} \cup \{z_{4,3},z_{4,4},y_{4,6},y_{4,9},y_{4,11},x_{4,3},x_{4,5},x_{4,7},x_{4,10},x_{4,13},x_{4,20},w_{4,2},w_{4,5},w_{4,14},v_{4,2},v_{4,5}\} \cup \{w_{5,1},v_{5,3}\} \]

\[ S_4 = \{w_{1,1},v_{1,3}\} \cup \{x_{2,9},x_{2,14},w_{2,3},w_{2,10},v_{2,1}\} \cup \{z_{3,3},z_{3,5},z_{3,2},y_{3,4},y_{3,7},y_{3,10},y_{3,13},y_{3,15},x_{3,2},x_{3,11},x_{3,15},x_{3,17},x_{3,19}\} \]
From Theorem 3, it is clear that every two vertices in $B^{(1)}_{60}$ have different color codes. Then we can conclude that every two vertices in $B^{(p)}_{60}$, for $2 \leq p \leq 5$ also have different color codes. Now, consider two vertices in different $a \in V(B^{(k)}_{60})$ and $b \in V(B^{(t)}_{60})$ for $1 \leq k, t \leq 5, k \neq t$, where $c_1(a) = c_1(b)$. We will show that $c_1(a) \neq c_1(b)$. Without loss of generalities, let $a \in V(B^{(1)}_{60})$ and $b \in V(B^{(2)}_{60})$, with $c(a) = c(b) = 1$. For every two vertices in $V(B^{(k)}_{60})$ and $V(B^{(t)}_{60})$ for $1 \leq k, t \leq 5$ and $k \neq t$, the proofs are similar. If $c(a) = 1$ then the corresponding vertices in $B^{(2)}_{60}$ is given color 2. For example, if $c(x_{1,12}) = 1$ then $c(x_{2,12}) = 2$. Similarly, if $c(b) = 1$ then the corresponding vertices in $B^{(1)}_{60}$ is given color 5. For example, if $c(x_{2,13}) = 1$ then $c(x_{1,13}) = 5$. Because the distance to the vertex of color 5 are different, $d(x_{1,12}, x_{1,13}) = 1$, and $d(x_{2,12}, x_{2,13}) = 4$

then $c_1(a) \neq c_1(b)$. Therefore, every two vertices in $H = \bigcup_{s=1}^{m} B^{(s)}_{60}$ have different color codes, and $\chi^*_L(H) \leq 5$.

In Example 1 we give the 5-locating coloring of $H = \bigcup_{s=1}^{5} B^{(s)}_{60}$.

**Example 1.** Using the 5-locating coloring defined in Theorem 4, we will show that every two vertices have different color codes. Consider the following cases.

**Case 1.** Vertices with color 1 in $B^{(s)}_{60}$ for $1 \leq s \leq 5$. Without loss of generality, let $c(w_{1,8}) = c(w_{2,5}) = c(w_{3,4}) = c(w_{4,3}) = c(w_{5,9}) = 1$. Then their color codes are $c_1(w_{1,8}) = (0,1,2,2,1)$, $c_1(w_{2,5}) = (0,1,1,2,3)$, $c_1(w_{3,4}) = (0,1,2,1,1)$, $c_1(w_{4,3}) = (0,2,1,2,1)$ and $c_1(w_{5,9}) = (0,1,3,1,1)$.

**Case 2.** Vertices with color 2 in $B^{(s)}_{60}$ for $1 \leq s \leq 5$. Without loss of generality, let $c(w_{1,7}) = c(w_{2,8}) = c(w_{3,5}) = c(w_{4,1}) = c(w_{5,10}) = 2$. Then their color codes are $c_1(w_{1,7}) = (1,0,2,2,1,2)$, $c_1(w_{2,8}) = (1,0,1,2,2)$, $c_1(w_{3,5}) = (3,0,1,2,2)$, $c_1(w_{4,1}) = (1,0,1,2,1)$ and $c_1(w_{5,10}) = (1,0,4,2,2)$.

**Case 3.** Vertices with color 3 in $B^{(s)}_{60}$ for $1 \leq s \leq 5$. Without loss of generality, let $c(w_{1,10}) = c(w_{2,9}) = c(w_{3,8}) = c(w_{4,5}) = c(w_{5,1}) = 3$. Then their color codes are $c_1(w_{1,10}) = (2,1,0,4,2)$, $c_1(w_{2,9}) = (1,1,0,1,3)$, $c_1(w_{3,8}) = (2,1,0,1,2)$, $c_1(w_{4,5}) = (2,3,0,1,2)$ and $c_1(w_{5,1}) = (1,1,0,1,2)$.

**Case 4.** Vertices with color 4 in $B^{(s)}_{60}$ for $1 \leq s \leq 5$. Without loss of generality, let $c(w_{1,1}) = c(w_{2,3}) = c(w_{3,4}) = c(w_{4,6}) = c(w_{5,5}) = 4$. Then their color codes are $c_1(w_{1,1}) = (2,1,1,0,1)$, $c_1(w_{2,3}) = (1,2,1,0,2)$, $c_1(w_{3,4}) = (3,1,2,0,1)$, $c_1(w_{4,6}) = (1,2,2,0,1)$ and $c_1(w_{5,5}) = (1,2,3,0,1)$.

**Case 5.** Vertices with color 5 in $B^{(s)}_{60}$ for $1 \leq s \leq 5$. Without loss of generality, let $c(w_{1,14}) = c(w_{2,1}) = c(w_{3,10}) = c(w_{4,5}) = c(w_{5,9}) = 1$. Then their color codes are $c_1(w_{1,14}) = (1,1,3,2,0)$, $c_1(w_{2,1}) = (1,2,1,1,0)$, $c_1(w_{3,10}) = (4,2,2,1,0)$, $c_1(w_{4,5}) = (1,3,1,1,0)$ and $c_1(w_{5,9}) = (1,2,2,1,0)$.

Graph $H = \bigcup_{s=1}^{5} B^{(s)}_{60}$ and its 5-locating coloring is given in Figure 1.
4. CONCLUSIONS

In this paper, we modified the locating chromatic 5-coloring of one Buckminsterfullerene to construct the locating chromatic 5-coloring of the disjoint union of the Buckminsterfullerene graphs, denoted by $H = \bigcup_{s=1}^{5} B_{60}^{(s)}$.

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REFERENCES


