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# The Locating Chromatic Number for the New Operation on Generalized Petersen Graphs $N_{P(m,1)}$

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**ABSTRACT**

The locating chromatic number is a graph invariant that quantifies the minimum number of colors required for proper vertex coloring, ensuring that any two vertices with the same color have distinct sets of neighbors. This study introduces a new operation on generalized Petersen graphs denoted by $N_{P(m,1)}$, exploring its impact on locating chromatic numbers. Through systematic analysis, we aim to determine the specific conditions under which this operation influences the locating chromatic number and provide insights into the underlying graph-theoretical properties. The method for computing the locating chromatic number for the new operation on generalized Petersen graphs, denoted by $N_{P(m,1)}$, entails determining the lower and upper limits. The results indicate that the locating chromatic number for the new operation on the generalized Petersen graph is 4 for $m = 4$ and 5 for $m \geq 5$. The findings contribute to a broader understanding of graph coloring.

**Keywords**: locating chromatic number, new operation, generalized Petersen graphs

## INTRODUCTION

The discipline of graph theory, which falls under discrete mathematics, offers a robust framework for representing relationships and connections among diverse entities. One intriguing aspect of graph theory is the study of graph colorings, where vertices or edges are assigned colors according to certain rules. The concept of chromatic numbers and related variations has been a focal point in this field.

The notion of locating chromatic numbers for graphs was first proposed in 2002 (Chartrand et al., 2002) blending two key concepts in graph theory: graph coloring and the partition dimension of graphs. Computing the locating chromatic number for arbitrary graphs is an NP-complete problem, implying the absence of an efficient algorithm for its calculation. Nonetheless, numerous studies have focused on specific classes of graphs to address this challenge.

Various researchers have investigated the locating chromatic number of graph operation results, such as the Kneser graphs (Ali Behtoei & Omoomi, 2011), the corona product of two graphs (Baskoro & Purwasih, 2012), the joint product of two graphs (A. Behtoei & Anbarloei, 2014), and the Cartesian product of two complete graphs (Ali Behtoei & Omoomi, 2016), and have provided their findings.

In 2017 (Asmiati et al., 2017) found Petersen graphs where the locating chromatic number is either four or five. Next, Welyanti et al investigate the locating chromatic number of a graph comprising two components (Welyyanti et al., 2017). Furthermore, a methodology has been devised to calculate the locating chromatic number for origami graphs $O_m$

and their divisions (one point on the outside of the edge) (Irawan et al., 2021). Subsequently (Asmiati et al., 2023) established the locating chromatic numbers for specific operations involving origami graphs.

In 2021, (Inayah et al., 2021) established the precise locating chromatic number for book graphs. Subsequently (Sudarsana et al., 2022), determined locating chromatic number values for m-shadows of complete multipartite graphs and paths was accomplished, with certain findings deemed optimal. The chromatic number of the pizza graph has also been found, we get 4 for $n = 3$ and $n$ for $n \geq 5$ (Surbakti et al., 2023).

The subsequent description of the generalized Petersen graph is extracted from the following source (Watkins, 1969).

**Definition 1.1.** Let $\{y_1, y_2, \dots, y_m\}$ vertices located on the outer cycle and $\{x_1, x_2, \dots, x_m\}$ vertices located on the inner cycle for $m \geq 3$. The generalized Petersen graph $P(m,l)$, $m \geq 3$ and $1 \leq l \leq \lfloor (m-1)/2 \rfloor$, $1 \leq i \leq m$ represents a graph with a total of 2n vertices $\{x_i\} \cup \{y_i\}$, and edges $\{x_i x_{i+1}\} \cup \{y_i y_{i+l}\} \cup \{x_i y_i\}$. Next, we will introduce a new operation for the generalized Petersen graph, denoted as $N_{P(m,1)}$.

In the subsequent sections (Chartrand et al., 2002) delineated the fundamental principles of the locating chromatic number of a graph. The set of vertices adjacent to vertex k in a connected graph $H$, denoted by $N(f)$, is called the neighborhood of vertex $f$.

**Theorem 1.1**. Let $r$ denote a locating coloring in a connected graph $H$. If $f$ and $g$ are distinct vertices of $H$ such that $d(f,z) = d(g,z)$ for all $z \in V(H) - \{f,g\}$, then $r(f) \neq r(g)$. Specifically, if $f$ and $g$ are vertices that are not adjacent, and their neighborhoods are different ($N(f) \neq N(g)$), then their assigned colors under $r$ must also be different ($r(f) \neq r(g)$).

Specifically, our exploration focuses on the new operation of generalized Petersen graphs, which extends the classical ones. Generalized Petersen graphs have gained prominence due to their rich structural properties and diverse applications in various scientific disciplines.

The primary objective of this study is to ascertain the locating chromatic number resulting from applying a novel operation on generalized Petersen graphs. Subsequently, we introduce this new operation, laying the groundwork for exploring the locating chromatic number.

## MATERIAL AND METHOD

The method utilized to determine the locating chromatic number of the newly introduced operation on the generalized Petersen graph consists of the following stages:

The first stage is defining the new operation of the generalized Petersen graph.

**Definition 2.1** Let a new operation of generalized Petersen graph $N_{P(m,1)}$, for $m \geq 3$ is a graph with $V(N_{P(m,1)}) = \{x_j, x_{m+j}, y_j, y_{m+j} \;:\; j \in \{1,2 \dots, m\}\}$ and $E(N_{P(m,1)})$=$\{x_j x_{j+1}, x_{m+j} x_{m+j+1}, y_j y_{j+1}\; y_{m+j} y_{m+j+1} \;:\; j \in \{1,2,\dots, m-1\}\} \cup \{x_m x_1, x_{2m} x_{2m+1}, y_m y_1, y_{2m} y_{2m+1}\} \cup \{x_j y_j, x_{m+j} y_{m+j} \;:\; j \in \{1,2 \dots, m\}\} \cup \{x_j x_{m+j} : j \in \{1,2, \dots, m\}\}$

The second stage involves determining the lower limit of the new operation on the generalized Petersen graph by specifying the minimum number of colors required to fulfill the locating coloring criteria.

The following theorems provide the locating chromatic numbers for both the cycle graph and the generalized Petersen graph $P(m, 1)$.



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**Theorem 2.1** (Chartrand et al., 2003), $\chi_L(C_m) = \begin{cases} 3, & \text{for odd } m \\ 4, & \text{otherwise.} \end{cases}$

**Theorem 2.2** (Asmiati et al., 2017)**,** $\chi_L(P(m,1)) = \begin{cases} 4, & \text{for odd } m \\ 5, & \text{for even } m. \end{cases}$

The third stage involves determining the upper limit of the locating chromatic number for the new operation applied to the generalized Petersen graph. These upper limits can be established by constructing colorings that satisfy the location requirements.

In the fourth stage, the results are formulated into theorems and proven.

## RESULT AND DISCUSSION

The following theorem establishes the precise locating chromatic number for $N_{P(m,1)}$.

**Theorems 3.1** Let $N_{P(m,1)}$ be a new operation of generalized Petersen graphs for $m \geq 3$. Then,

$$\chi_L(N_{P(m,1)}) = \begin{cases} 4, & \text{for } m = 3 \\ 5, & \text{for } m \geq 4 \end{cases}$$

**Proof.** A new operation for the generalized Petersen graph, denoted as $N_{P(m,1)}$. Let $N_{P(m,1)}$, for $m \geq 3$ is a graph with $V(N_{P(m,1)}) = \{x_j, x_{m+j}, y_j, y_{m+j}: j \in \{1, \dots, m\}\}$ and $E(N_{P(m,1)}) = \{x_j x_{j+1}, x_{m+j} x_{m+j+1}, y_j y_{j+1}, y_{m+j} y_{m+j+1} : j \in \{1, \dots, m-1\}\} \cup \{x_m x_1, x_{2m} x_{2m+1}, y_m y_1, y_{2m} y_{2m+1}\} \cup \{x_j y_j, x_{m+j} y_{m+j} : j \in \{1, \dots, m\}\} \cup \{x_j x_{m+j}$ $j \in \{1, \dots, m\}\}$. We differentiate between two cases :

**Case 1.** $\chi_L(N_{P(3,1)}) = 4$

First, we will establish the lower limit of $\chi_L(N_{P(3,1)})$. Considering that the $N_{P(3,1)}$ loads multiple even cycles, then by Theorem 2.1 $\chi_L(N_{P(3,1)}) \geq 4$. So $\chi_L(N_{P(3,1)}) \geq 4$, for $m \geq 3$.

Next, we define a 4-coloring $r$ of $N_{P(3,1)}$ as follows:

$R_1 = \{x_3, x_5, y_6\}$
$R_2 = \{x_5, x_6, y_3\}$
$R_3 = \{x_1, y_2, y_4\}$
$R_4 = \{x_1, x_4, y_1\}$.

With the application of coloring $t$, we derive the color codes for $V(N_{P(3,1)})$ as follow: $t_\Pi(x_1) = (1,2,0,1)$; $t_\Pi(x_2) = (1,2,1,0)$; $t_\Pi(x_3) = (0,1,1,1)$; $t_\Pi(x_4) = (1,1,1,0)$; $t_\Pi(x_5) = (0,1,2,1)$; $t_\Pi(x_6) = (1,0,2,1)$; $t_\Pi(y_1) = (2,1,1,0)$; $t_\Pi(y_2) = (2,1,0,1)$; $t_\Pi(y_3) = (1,0,1,1)$; $t_\Pi(y_4) = (1,1,0,1)$; $t_\Pi(y_5) = (1,0,1,2)$; $t_\Pi(y_6) = (0,1,12)$. All the vertices have different color codes, so $r$ is a 4-locating coloring of $N_{P(3,1)}$. Thus $\chi_L(N_{P(3,1)}) \leq 4$.

**Case 2.** $\chi_L(N_{P(m,1)}) = 5$, for $m \geq 4$

We differentiate between two subcases:

**Subcase 1.** For even $m \geq 4$

we will establish the lower limit of $\chi_L(N_{P(m,1)})$, for even $m \geq 4$. Considering that $N_{P(m,1)}$ containing $P(m,1)$, then by Theorem 2.2 $\chi_L(N_{P(m,1)}) \geq 5$. So $\chi_L(N_{P(m,1)}) \geq 5$, for even $m \geq 4$.

Let $r$ be a coloring of $N_{P(m,1)}$ for even $m \geq 4$, the partition $\Pi$ of $V(N_{P(m,1)})$:

$R_1$ $=\{y_1, y_{m+1}\}$;
$R_2$ $=\{y_j | \text{for even } j, \ j \in \{2, \dots, m-2\}\} \cup \{x_j | \text{for odd } j, j \in \{1, \dots, m-1\}\} \cup \{y_{m+j} | \text{for odd } j, j \in \{3, \dots, m-1\}\} \cup \{x_{m+j} | \text{for even } j, j \in \{2, \dots, m\}\}$;
$R_3$ $=\{y_j | \text{for odd } j, \ j \in \{3, \dots, m-1\}\} \cup \{x_j | \text{for even } j, j \in \{2, \dots, m-2\}\} \cup \{y_{m+j} | \text{for even } j, j \in \{2, \dots, m-2\}\} \cup \{x_{m+j} | \text{for odd } j, j \in \{1, \dots, m-1\}\}$;
$R_4$ $=\{y_m, y_{2m}\}$;
$R_5$ $=\{x_m\}$.


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The color codes for each vertex of $V(N_{P(m,1)})$ are:

$$r_\Pi(x_j) = \begin{cases} j, & \text{for } (1)^{st}\text{component}, j \le \frac{m}{2} \\ (m+1-j), & \text{for } (1)^{st}\text{component}, j > \frac{m}{2} \\ 0, & \text{for } (2)^{nd}\text{component, odd } j, j \in \{1,\dots,m-1\} \\ & \text{for } (3)^{th}\text{component, even } j, j \in \{2,\dots,m-2\} \\ & \text{for } (5)^{th}\text{component}, j = m \\ (j+1), & \text{for } (4)^{th}\text{component}, \ j \in \left\{1,\dots,\frac{m}{2}\right\} \\ (m+1-j), & \text{for } (4)^{th}\text{component}, \ j \in \left\{\frac{m}{2}+1,\dots,m\right\} \\ j, & \text{for } (5)^{th}\text{component}, \ j \in \left\{1,\dots,\frac{m}{2}\right\} \\ (m-j), & \text{for } (5)^{th}\text{component}, \ j \in \left\{\frac{m}{2}+1,\dots,m-1\right\} \\ 1, & \text{otherwise.} \end{cases}$$

$$r_\Pi(y_j) = \begin{cases} 0, & \text{for } (1)^{st}\text{component}, j = 1 \\ & \text{for } (4)^{th}\text{component}, j = m \\ & \text{for } (2)^{nd}\text{component, even } j, \ j \in \{2,\dots,m-2\} \\ & \text{for } (3)^{th}\text{component, odd } j, \ j \in \{3,\dots,m-1\} \\ (j-1), & \text{for } (1)^{st}\text{component }, \ j \in \left\{1,\dots,\frac{m}{2}\right\} \\ (m+1-j), & \text{for } (1)^{st}\text{component}, \ j \in \left\{\frac{m}{2}+1,\dots,m\right\} \\ j, & \text{for } (4)^{th}\text{component}, \ j \in \left\{1,\dots,\frac{m}{2}\right\} \\ (m-j), & \text{for } (4)^{th}\text{component}, \ j \in \left\{\frac{m}{2}+1,\dots,m-1\right\} \\ (j+1), & \text{for } (5)^{th}\text{component}, \ j \in \left\{1,\dots,\frac{m}{2}\right\} \\ (m+1-j), & \text{for } (5)^{th}\text{component}, \ j \in \left\{\frac{m}{2}+1,\dots,m\right\} \\ 1, & \text{otherwise.} \end{cases}$$

$$r_\Pi(y_{m+j}) = \begin{cases} (j-1), & \text{for } (1) \quad \text{component}, \ j \in \left\{2,\dots,\frac{m}{2}\right\} \\ (m+1-j), & \text{for } (1) \quad \text{component}, \ j \in \left\{\frac{m}{2}+1,\dots,m\right\} \\ 0, & \text{for } (2) \quad \text{component, odd } j, \ j \in \{2,\dots,m\} \\ & \text{for } (3) \quad \text{component, even } j, \ j \in \{1,\dots,m-1\} \\ & \text{for } (1)^{st}\text{component}, \ j = 1 \\ & \text{for } (4) \quad \text{component}, \ j = m \\ j, & \text{for } (4) \quad \text{component}, \ j \in \left\{1,\dots,\frac{m}{2}\right\} \\ (m-j), & \text{for } (4) \quad \text{component}, \ j \in \left\{\frac{m}{2}+1,\dots,m-1\right\} \\ (j+2), & \text{for } (5)^{th}\text{component}, \ j \in \left\{1,\dots,\frac{m}{2}\right\} \\ (m+2-j), & \text{for } (5)^{th}\text{component}, \ j \in \left\{\frac{m}{2}+1,\dots,m-1\right\} \\ 1, & \text{otherwise.} \end{cases}$$

$$r_{\Pi}(x_{m+j}) = \begin{cases} j, & \text{for } (1)^{st}\text{component}, j \leq \frac{m}{2} \\ (m+2-j), & \text{for } (1)^{st}\text{component}, j > \frac{m}{2} \\ 0, & \text{for } (2)^{nd}\text{component, odd } j, j \in \{2, \dots, m\} \\ & \text{for } (3)^{th}\text{component, even } j, j \in \{1, \dots, m-1\} \\ (j+1), & \text{for } (4)^{th}\text{and } (5)^{th}\text{component}, \ j \in \left\{1, \dots, \frac{m}{2}\right\} \\ (m+1-j), & \text{for } (4)^{th}\text{and } (5)^{th}\text{component}, \ j \in \left\{\frac{m}{2}+1, \dots, m\right\} \\ 1, & \text{otherwise.} \end{cases}$$

Given that for even $m$, each vertex possesses a distinct color code, $r$ serves as a locating coloring for $N_{P(m,1)}$. So $\chi_L(N_{P(m,1)}) \leq 5$, for even $m \geq 4$.

**Subcase 2.** For odd $m \geq 5$

First, we will establish the lower limit of $\chi_L(N_{P(m,1)})$, for odd $m \geq 5$. Considering that $N_{P(m,1)}$ containing $P(m,1)$, then by Theorem 2.2 $\chi_L(N_{P(m,1)}) \geq 4$. Then, let $r$ be a locating coloring using 4 colors. It can be seen that the barbell graph $(N_{P(m,1)})$ has two points with the same color code, this is a contradiction. So $\chi_L(N_{P(m,1)}) \geq 5$, for odd $m \geq 5$.

Let $r$ be a coloring of $N_{P(m,1)}$ for odd $m \geq 5$, the partition $\Pi$ of $V(N_{P(m,1)})$:

$R_1 = \{y_1, y_{m+1}\}$;
$R_2 = \{y_j | \text{for even } j, \ j \in \{2, \dots, m-1\}\} \cup \{x_j | \text{for odd } j, \ j \in \{1, \dots, m-2\}\} \cup \{y_{m+j} | \text{for odd } j, \ j \in \{3, \dots, m\}\} \cup \{x_{m+j} | \text{for even } j, \ j \in \{2, \dots, m-1\}\}$;
$R_3 = \{y_j | \text{for odd } j, j \in \{3, \dots, m\}\} \cup \{x_j | \text{for even } j, j \in \{2, \dots, m-1\}\} \cup \{y_{m+j} | \text{for even } j, \ j \in \{2, \dots m-1\}\} \cup \{x_{m+j} | \text{for odd } j, j \in \{1, \dots, m-2\}\}$;
$R_4 = \{x_m\}$;
$R_5 = \{x_{2m}\}$.

The color codes for each vertex of $V(N_{P(m,1)})$ are:

$$r_{\Pi}(x_j) = \begin{cases} j, & \text{for } (1)^{st}\text{component}, j \leq \frac{(m+1)}{2} \\ (m+2-j), & \text{for } (1)^{st}\text{component}, j > \frac{(m+1)}{2} \\ 0, & \text{for } (2)^{nd}\text{component, odd } j, j \in \{1, \dots, m-2\} \\ & \text{for } (3)^{th}\text{component, even } j, j \in \{2, \dots, m-1\} \\ & \text{for } (4)^{th}\text{component}, j = m \\ j, & \text{for } (4)^{th}\text{component}, j \in \left\{1, \dots, \frac{(m-1)}{2}\right\} \\ (m-j), & \text{for } (4)^{th}\text{component}, j \in \left\{\frac{(m+1)}{2}, \dots, m-1\right\} \\ (j+1), & \text{for } (5)^{th}\text{component}, j \in \left\{1, \dots, \frac{(m-1)}{2}\right\} \\ (m+1-j), & \text{for } (5)^{th}\text{component}, j \in \left\{\frac{(m+1)}{2}, \dots, m\right\} \\ 1, & \text{otherwise.} \end{cases}$$


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$$r_\Pi(y_j) = \begin{cases} 0, & \text{for } (1)^{st} \text{component}, j = 1 \\ & \text{for } (2)^{nd} \text{component, even } j, j \in \{2, \dots, m-1\} \\ & \text{for } (3)^{th} \text{component, odd } j, j \in \{3, \dots, m\} \\ (j-1), & \text{for } (1)^{st} \text{component}, j \in \left\{1, \dots, \frac{(m+1)}{2}\right\} \\ (m+1-j), & \text{for } (1)^{st} \text{component}, j \in \left\{\frac{(m+3)}{2}, \dots, m\right\} \\ (j+1), & \text{for } (4)^{th} \text{component}, j \in \left\{1, \dots, \frac{(m-1)}{2}\right\} \\ (m+1-j), & \text{for } (4)^{th} \text{component}, j \in \left\{\frac{(m+1)}{2}, \dots, m\right\} \\ (j+2), & \text{for } (5)^{th} \text{component}, j \in \left\{1, \dots, \frac{(m-1)}{2}\right\} \\ (m+2-j), & \text{for } (5)^{th} \text{component}, j \in \left\{\frac{(m+1)}{2}, \dots, m\right\} \\ 1, & \text{otherwise.} \end{cases}$$

$$r_\Pi(x_{m+j}) = \begin{cases} j, & \text{for } (1)^{st} \text{component}, j \le \frac{(m+1)}{2} \\ (m+2-j), & \text{for } (1)^{st} \text{component}, j > \frac{(m+1)}{2} \\ 0, & \text{for } (2)^{nd} \text{component, even } j, j \in \{2, \dots, m-1\} \\ & \text{for } (3)^{th} \text{component, odd } j, j \in \{1, \dots, m-2\} \\ & \text{for } (5)^{th} \text{component}, j = m \\ (j+1), & \text{for } (4)^{th} \text{component}, j \in \left\{1, \dots, \frac{(m-1)}{2}\right\} \\ (m+1-j), & \text{for } (4)^{th} \text{component}, j \in \left\{\frac{(m+1)}{2}, \dots, m\right\} \\ j, & \text{for } (5)^{th} \text{component}, j \in \left\{1, \dots, \frac{(m-1)}{2}\right\} \\ (m-j), & \text{for } (5)^{th} \text{component}, j \in \left\{\frac{(m+1)}{2}, \dots, m-1\right\} \\ 1, & \text{otherwise.} \end{cases}$$

$$r_\Pi(y_{m+j}) = \begin{cases} (j-1), & \text{for } (1)^{st} \text{component}, j \in \left\{2, \dots, \frac{(m+1)}{2}\right\} \\ (m+1-j), & \text{for } (1)^{st} \text{component}, j \in \left\{\frac{(m+3)}{2}, \dots, m\right\} \\ 0, & \text{for } (2)^{nd} \text{component, odd } j, j \in \{3, \dots, m\} \\ & \text{for } (3)^{th} \text{component, even } j, j \in \{2, \dots, m-1\} \\ & \text{for } (1)^{st} \text{component}, j = 1 \\ & \text{for } (5)^{th} \text{component}, j = m \\ (j+2), & \text{for } (4)^{th} \text{component}, j \in \left\{1, \dots, \frac{(m-1)}{2}\right\} \\ (m+1-j), & \text{for } (4)^{th} \text{component}, j \in \left\{\frac{(m+1)}{2}, \dots, m-1\right\} \\ (j+1), & \text{for } (5)^{th} \text{component}, j \in \left\{1, \dots, \frac{(m-1)}{2}\right\} \\ (m+1-j), & \text{for } (5)^{th} \text{component}, j \in \left\{\frac{(m+1)}{2}, \dots, m\right\} \\ 1, & \text{otherwise.} \end{cases}$$

Given that for even $m$, each vertex possesses a different color code, $r$ serves as a locating coloring of $N_{P(m,1)}$. So $\chi_L(N_{P(m,1)}) \leq 5$, for even $m \geq 4$. From the several cases above, the proof is complete. □

## CONCLUSION

This research aims to explore and determine the locating-chromatic number resulting from a new operation on the generalized Petersen graph. The Petersen graph is one of the graphs frequently used in graph theory studies due to its unique properties and wide range of applications. In this study, a new operation is applied to the generalized Petersen graph to observe how these changes affect the graph's locating-chromatic number. The approach used involves determining the upper and lower limits of the locating chromatic number. The outcome derived from this study is :

i. $\chi_L\left(N_{P(3,1)}\right) = 4$
ii. $\chi_L\left(N_{P(m,1)}\right) = 5$, for $m \geq 4$.

Consequently, further investigation into the impacts of additional operations on generalized Petersen graphs constitutes intriguing subsequent research.

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