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The Strong Rainbow Connection between the Number of Joined Ladder Graph and Trivial Graph

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ABSTRACT

Let $G = (V, E)$ be a nontrivial, finite, and connected graph. A function c from E to $\{1, 2, \ldots, k\}$, $k \in \mathbb{N}$, can be considered as a rainbow k-coloring if every two vertices x and y in G has an $x - y$ path. Therefore, no two of the path's edges receive the same hue; this condition is what we call a "rainbow path". The smallest positive integer k, designated by "rc"(G), is the G rainbow connection number. Thus, G has a rainbow-k coloring. Meanwhile, the c function is considered as a strong rainbow k-coloring within the condition for every two vertices x and y in G have an $x - y$ rainbow path whose length is the distance between x and y. The smallest positive integer k, such as G, has a strong rainbow k-coloring; such a condition is called a strong rainbow connection number of G, denoted by src(G). In this research, the (strong) rainbow connection number is determined from the graph resulting from the join operation between the ladder graph and the trivial graph.

A. INTRODUCTION

This article discusses simple, linked, and finite graphs. In the context of graphs, the idea of "rainbow connection" was initially proposed by Chartrand et al. (2008). Let $G = (V, E)$ be a graph with vertex set V and edge set E. A coloring c: $E \rightarrow \{1, 2, \ldots, k\}$, $k \in \mathbb{N}$, thus, the adjacent edges can share identical color. Let x and y be in V. A $x - y$ path in G is determined as a rainbow path if each edge of the path has a different color. Meanwhile, G is determined as a rainbow connection if every two vertices x and y has a rainbow path. Rainbow coloring is the term used to describe an edge color on G that connects to the G rainbow. If the c function employs -k colors, it constitutes the rainbow-k coloring. The smallest positive integer k, designated by "rc"(G), is the rainbow connection number of G. Thus, G has a rainbow-k coloring. Meanwhile, the $x - y$ rainbow path is considered as the $x -$y rainbow geodesic if the length of the path constitutes the distance between x and y. G becomes a strong rainbow connection if every two vertices x and y have an x – y rainbow geodesic. Strong rainbow coloring is edge coloring on G that gives G a strong rainbow connection. If the c function uses k colors, it is said to have a strong rainbow-k coloring. The lowest positive integer k is the strong rainbow connection number of G, indicated by "src"(G). As a result, G has a strong rainbow-k coloring, and rc(G) $is \leq$ src(G) for any linked graph G.

On condition that G is a rainbow connection, the least diam(G) colors are necessary; the diam(G) refers to the G's diameter. On the other hand, rainbow coloring is defined by G if each of its edges is colored differently. Hence, the formula is as follows.

$$\text{diam}\,(G) \leq \text{rc}(G) \leq \text{src}(G) \leq m. \quad (1)$$

Several previous studies have investigated both the weak and strong rainbow connections numbers. Chartrand et al. (2008) have determined some $\mathrm{rc}(G)$ and $\mathrm{src}(G)$ of connected G graphs, as follows.

Proposition 1. Let G be an m-size dimensional nontrivial connected graph.

a) $\mathrm{src}(G) =$ If and only if G is a full graph, then 1 applies.
b) $\mathrm{rc}(G) =$ If only if $\mathrm{src}(G)$, then 2 applies.
c) $\mathrm{rc}(G) =$ If only if G is a tree, then m applies.

The strong rainbow connection number of stellar graphs, which is a corona product of a trivial graph and an m -copies ladder graph, was discovered by Shulhany and Salman back in 2016 (Shulhany & Salman, 2016). On the other hand, Fitrianda et al. (2018) have determined a generalized triangular ladder graph's rainbow connection number and strong rainbow connection number. Meanwhile, (L. Chen et al., 2018) present some results of the six rainbow connection parameters. Other previous studies have found other results of (strong) rainbow connection of graph (H. Li et al., 2011; Schiermeyer, 2011).

The concept of rainbow connectivity can apply to data security. Confidential information should be protected from being transferred from one party to another. The security system must be able to prohibit not just unauthorized users from accessing the system, but also users who are already signed in from performing actions that they are not permitted to perform (Morris & Thompson, 1979). A security cracking method known as a rainbow table employs a precalculated table of inverted password hashes to decipher passwords in databases. The user is verified whether the values match. The rainbow table database is utilized to decrypt the password hash and get authentication (Zhang, Tan & Yu, 2013). To minimize data leakage from such confidential information, each agent should have a different password when transferring information. As a result, a lot of passwords are needed. Fortunately, the rainbow connection concept enables to require a minimum number of passwords so that two agents can exchange information with different passwords.

Apart from this motivation, the concept of rainbow connection is interesting to study. Many researchers have developed the concept of rainbow connectivity by applying it to various types of graphs. One of them is by performing operations on several graphs and specifying $\mathrm{rc}(G)$ and $\mathrm{src}(G)$ on those graphs. Li and Sun (2012) have obtained several results of rainbow connection number of graph products, comprising lexicographic products, join, and cartesian products, etc. Meanwhile, Resty and Salman (2015) have determined the rainbow connection number of the corona product of the n-crossed prism graph with the trivial graph. Septyanto and Sugeng (2017) give lower and upper limits for rainbow connection numbers and strong rainbow connection numbers by joining two graphs based on individual graph parameters: the number of vertices of degree 0, maximum degree, independent dominance number, clique number, and independent number.

Other related studies have been done by Li and Ma (2017). They have calculated the rainbow connection number of operating graphs by using several ways such as a) includes a union of graphs, b) adds and removes edges, and c) adds vertices. Strong and accurate values of rainbow connection numbers, as well as their upper bounds of comb product, path, triangular book, circular, or fan graphs are discussed by Dafik et al. (2018). In addition, several previous studies focus on examining rainbow connection numbers from operating graphs (Antoro, 2016; Basavaraju et al., 2014; X. Chen et al., 2019; Fitriani & Salman, 2016; Gembong & Agustin, n.d.; Gologranc et al., 2014; Liu, 2014; Maulani et al., 2019; Doan, Ha, and Schiermeyer, 2022).

This research determined a (strong) rainbow connection number from the graphs resulting from the joint operation of ladder graphs and trivial graphs. As we already know, in order for two agents to share information while using different passwords, the rainbow connection idea allows for the requirement of a minimum number of passwords. The concept of the rainbow link is intriguing to examine even without this reason. (Kartika, 2020) assert that the ladder

graph, denoted by L_n, is obtained from two duplicates of the path P_n, becoming $P_{n_1}$and P_{n_2}. The vertex of v_i on P_{n_1} is connected to the vertex of w_i on P_{n_2} by an edge, with $i = 1, 2, \dots, n$. The trivial graph refers to a graph with only one vertex, denoted K_1 (Diestel, 2005). Meanwhile, let G_1 and G_2 connected graphs. The process of joining two disconnected graphs G_1 and G_2, denoted by $G_1 \vee G_2$, is the graph with vertex set $V(G_1) \cup V(G_2)$, and edge set of $V(G_1) \cup V(G_2) \cup \{uv | u \in V(G_1), v \in V(G_2)\}$ (Li & Sun, 2012).

B. METHODS

This literature study consisted of several steps, which are as follows.

1. Drawing a graph from the joint ladder graph and the trivial graph

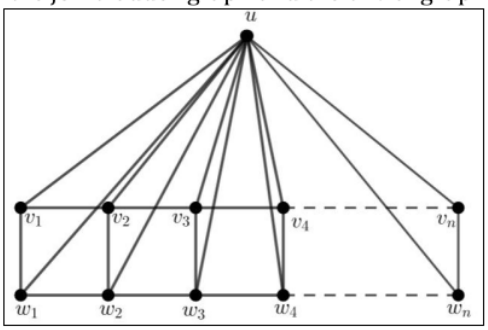


Figure 1. Graph $L_n \vee K_1$

2. Finding a rainbow coloring pattern for G and determining the accurate values of rc(G) and src(G).
3. Proving the rainbow connection number and the strong rainbow connection number of G. If rc(G) is = k, rc(G) $\geq k$ and rc(G) $\leq k$ should be done. To prove rc(G) $\geq k$, it is necessary to show a reason for the absence of rainbow coloring with $k - 1$ color or less. Proving rc(G) $\leq k$ by constructing a rainbow coloring in G using k colors.

C. RESULTS AND DISCUSSION

In this section, we calculate the strong rainbow connection number and the rainbow connection number of the following: the joined ladder graph and trivial graph; according to Theorem 1 and Theorem 2, respectively.

1. The Rainbow Connection Number of $L_n \vee K_1$

Theorem 1. *Let n be a positive integer with an $n \geq 3$. The rainbow connection number of $L_n \vee K_1$ is as follows.*

$$\text{rc}(L_n \vee K_1) = \begin{cases} 2, & \text{for } 3 \leq n \leq 4; \\ 3, & \text{for } n \geq 5. \end{cases}$$

Proof.

First, we prove a lower bound of rc($L_n \vee K_1$).

For $3 \leq n \leq 4$ is determined using the inequality (1), and we obtain rc($L_n \vee K_1$) ≥ 2.

For $n \geq 5$, suppose that rc($L_n \vee K_1$) ≤ 2.

Furthermore, there is a rainbow 2-coloring c^* for $(L_n \vee K_1)$. With no loss of generality, we assume that $c^*(uv_1) = 1$ *and* consider v_1 and v_5. Meanwhile, $d(v_1v_5) = 2$ and the only path from v_1 to v_5 with length 2 is v_1uv_5 it follows that $c^*(uv_5) = 2$. Then, we consider v_1 and w_3. $d(v_1w_3) = 2$ and the only path from v_1 to w_3 with length 2 is v_1uw_3, it follows that $c^*(u, w_3) = 2$. Then we consider w_3 and v_5. Meanwhile, $c^*(uv_5) = 2$, $c^*(uw_3) = 2$, and the only path from

w_3 to v_5 with length 2 is w_3uv_5 prove that $w_3 - v_5$ rainbow path was not found. We get a contradiction with $\mathrm{rc}(L_n \vee K_1) \geq 3$.

Next, we prove an upper bound of $\mathrm{rc}(L_n \vee K_1)$ by dividing the proof into two cases based on the value of n.

Case 1. $3 \leq n \leq 4$

The 2-coloring, $c : E(Pd_n) \to [1,2]$ is defined using the following formula.

$$c(e) = \begin{cases} 1, & \text{if } e \in \{uv_i, uw_i\} \text{ for } i \in \{1,2\} \text{ and } e \in \{v_iv_{i+1}, w_iw_{i+1}\} \text{ for } i \in [1,3]; \\ 2, & \text{if } e \in \{uv_i, uw_i\} \text{ for } i \in \{3,4\} \text{ and } e \in \{v_iw_i\} \text{ for } i \in [1,4]. \end{cases}$$

Case 2. $n \geq 5$

The 3-coloring, $c : E(Pd_n) \to [1,3]$ is defined using the following formula.

$$c(e) = \begin{cases} 1, & \text{if } e \in \{uv_i, uw_i\} \text{ for odd } i \in [1,n] \text{ and } e \in \{v_iw_i\} \text{ for } i \in [1,\mathrm{n}]; \\ 2, & \text{if } e = uv_i \text{ where } i \in [1,n] \text{ is even and } e = w_iw_{i+1} \text{ for } i \in [1,\mathrm{n}-1]; \\ 3, & \text{if } e = uw_i \text{ where } i \in [1,n] \text{ is even and } e = v_iv_{i+1} \text{ for } i \in [1,\mathrm{n}-1]. \end{cases}$$

The formulas show that every two adjacent vertices x and y in $V(L_n \vee K_1)$ have an $x - y$ rainbow path. Meanwhile, every x and y in $V(L_n \vee K_1)$ with $d(x,y) = 2$ for $3 \leq n \leq 4$ has an $x - y$ rainbow path (see Table 1). Every x and y in $V(L_n \vee K_1)$ with $d(x,y) = 2$ for $n \geq 5$ has an $x - y$ rainbow path (see Table 2). The proves of a lower bound and an upper bound of $\mathrm{rc}(L_n \vee K_1)$ complete the proof. ■

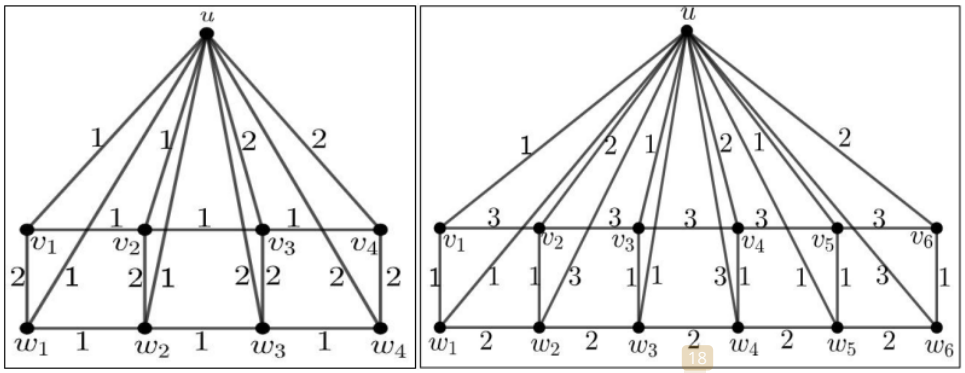
Table 1. An $x - y$ rainbow path on $L_n \vee K_1$ for $3 \leq n \leq 4$

x	y	Condition (i and j in $[1,n]$)	$x - y$ rainbow path
v_i	v_j	-	v_i, u, v_j
w_i	w_j	-	w_i, u, w_j
v_i	w_j	$j - i = 1$	v_i, w_i, w_j
		$i - j = 1$	v_i, w_{j+1}, w_j
		$\lvert j - i \rvert \neq 1$	v_i, u, w_j

Table 2. An $x - y$ rainbow path on $L_n \vee K_1$ for $n \geq 5$

x	y	Condition (i and j in $[1,n]$)	$x - y$ rainbow path
v_i	v_j	i and j have equal standing with $i < j$.	v_i, u, v_{j-1}, v_j
		i and j have varying parities.	v_i, u, v_j
w_i	w_j	i and j have equal standing with $i < j$.	w_i, u, w_{j-1}, w_j
		i and j have varying parities.	v_i, u, v_j
v_i	w_j	i and j have equal standing with $i < j$.	v_i, u, w_{j-1}, w_j
		i and j have varying parities.	v_i, u, v_j

The rainbow of 2-coloring of $L_4 \vee K_1$ and the rainbow of 3-coloring of $L_6 \vee K_1$ is illustrated in Figure 2: (a) and (b), respectively.



(a) (b)

Figure 2. (a) a rainbow of 2-coloring of $L_4 \vee K_1$; (b) a rainbow of 2-coloring of $L_6 \vee K_1$

2. The Strong 3-Rainbow Connection of $L_n \vee K_1$

Theorem 2. *Let n be a positive integer with an $n \geq 3$. The strong rainbow connection number of $L_n \vee K_1$ is calculated using the following formula.*

$$\operatorname{src}(L_n \vee K_1) = \left\lceil \frac{n}{2} \right\rceil, \text{ for } n \geq 3$$

Proof.

By using **Proposition 1. b)** and **Theorem 2**, we obtain $\operatorname{src}(L_n \vee K_1) = 2$ for $3 \leq n \leq 4$.

Let $k = \left\lceil \frac{n}{2} \right\rceil$. For $n \geq 5$, we discover that $\operatorname{src}(L_n \vee K_1) \geq k$. If $\operatorname{src}(L_n \vee K_1)$ is $\leq k-1$, a strong rainbow $k-1$ -coloring c^* exists. $L_n \vee K_1$ consists of a ladder graph $L_n \coloneqq v_1, v_2, \dots, v_n, w_1, w_2, \dots, w_n$ and u are adjacent to v_i and w_i for every $i = 1, 2, \dots, n$. An integer k also exists with $2k-1 \leq n \leq 2k$. Since $d(u) = 2n > 2(k-1)$, $A \subseteq V(L_n)$ exists so that $|A| = 3$ and all edges in $\{ut: t \in A\}$ have the same color. There are at least two vertices $t', t'' \in A$ with $d_{L_n}(t', t'') \geq 3$ and $d_{L_n \vee K_1}(t', t'') = 2$. Since t', u, t'' is the only geodesic in $L_n \vee K_1$, $t' - t''$ rainbow geodesic in $L_n \vee K_1$, does not exist; this is a contradiction. Thus, $\operatorname{src}(L_n \vee K_1)$ is $\geq k$.

Afterward, we show $\operatorname{src}(L_n \vee K_1) \leq k$.

The a k-coloring, $c : E(L_n \vee K_1) \to \{1,2, \dots, k\}$ is defined using the following formula.

$$c(e) = \begin{cases} 1, & \text{if } e \in \{v_i v_{i+1}, w_i w_{i+1}\} \text{ and odd } i \in [1, n-1]; \\ 2, & \text{if } e \in \{v_i v_{i+1}, w_i w_{i+1}\} \text{ and even } i \in [1, n-1]; \\ 3, & \text{if } e = v_i w_i \text{ and } i \in [1, n]; \\ j+1, & \text{if } e \in \{u v_i, u w_i\} \text{ and } i \in \{2j+1, 2j+2\} \text{ for } 0 \leq j \leq k-1. \end{cases}$$

Every x and y in $V(L_n \vee K_1)$ for $n \geq 5$ has an $x - y$ rainbow geodesic, as shown in Table 3. The results of the calculation complete the proof. ■

Table 3. An $x - y$ rainbow geodesic on $L_n \vee K_1$ for $n \geq 5$

x	y	Conditions (i and j in $[1, n]$)	$x - y$ rainbow geodesic
v_i	v_j	-	v_i, u, v_j
w_i	w_j	-	w_i, u, w_j

		$j - i = 1$	u_i, w_i, w_j
v_i	w_j	$i - j = 1$	v_i, w_{j+1}, w_j
		$\|j - i\| \neq 1$	v_i, u, w_j

A strong rainbow of 4-coloring of $L_8 \vee K_1$ is illustrated in Figure 3.

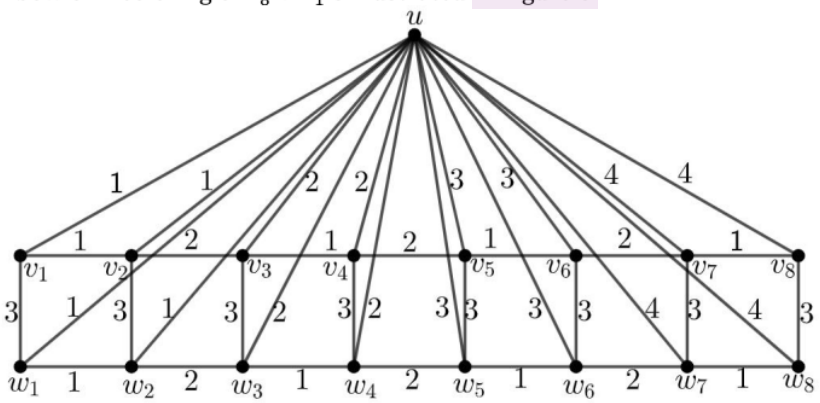


Figure 3. a strong rainbow of 4-coloring of $L_8 \vee K_1$

D. CONCLUSION AND SUGGESTIONS

This study has determined the exact value of (strong) rainbow connection number of joined ladder graph and trivial graph using the following formulas: $\mathrm{rc}(L_n \vee K_1) = 2$, for $3 \leq n \leq 4$ and $\mathrm{rc}(L_n \vee K_1) = 3$, for $n \geq 5$. This study has discovered $\mathrm{src}(L_n \vee K_1) = \left\lceil \frac{n}{2} \right\rceil$, for $n \geq 5$. Data security can benefit from the rainbow connectivity concept. Transferring confidential information from one party to another should be prevented. Each agent should use a distinct password when sharing information in order to reduce data leaking. With the rainbow connection concept, two agents can share information while using separate passwords because it enables the requirement of a minimum number of passwords.

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