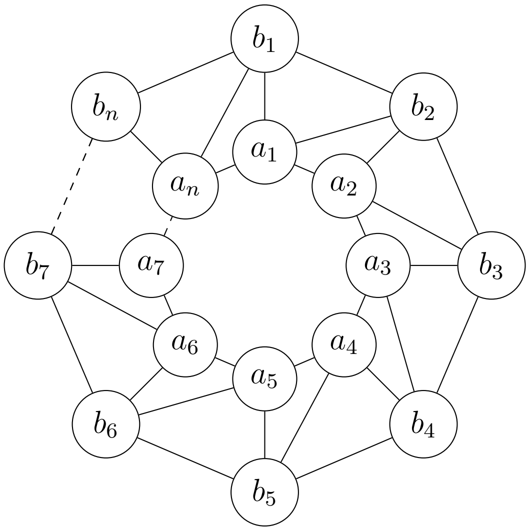


**Figure 6.** Antiprism Graph $A_n$

**Theorem 2** *For arbitrary positive integer $n \geq 3$, the cartesian product $P_2 \times A_n$ is edge odd graceful.*

*Proof.* Let the vertices and the edges of $P_2 \times A_n$ be

$$V(P_2 \times A_n) = \{a_i, b_i, A_i, B_i | i = 1, 2, \ldots, n\}$$

and

$$E(P_2 \times A_n) = \{a_i a_{(i+1) mod n} | i = 1, 2, \ldots, n\} \cup \{b_i b_{(i+1) mod n} | i = 1, 2, \ldots, n\} \cup$$
$$\{a_i b_i, a_i b_{(i+1) mod n} | i = 1, 2, \ldots, n\} \cup \{A_i A_{(i+1) mod n} | i = 1, 2, \ldots, n\} \cup$$
$$\{B_i B_{(i+1) mod n} | i = 1, 2, \ldots, n\} \cup \{A_i B_i, A_i B_{(i+1) mod n} | i = 1, 2, \ldots, n\} \cup$$
$$\{a_i A_i, b_i B_i | i = 1, 2, \ldots, n\}.$$

It is clear that $|V(P_2 \times A_n)| = 4n$ and $|E(P_2 \times A_n)| = 10n$ and hence we have $k = max\{|V(P_2 \times A_n)|, |E(P_2 \times A_n)|\} = 10n$. Now we construct an edge odd labeling

$$f_2 : E(P_2 \times A_n) \to \{1, 2, \ldots, 20n - 1\}$$

by

$$
\begin{aligned}
f_2(a_ia_{(i+1)modn}) &= 2n-2i+1\\
f_2(b_ib_{(i+1)modn}) &= 8n-2i+1\\
f_2(a_ib_{(i+1)modn}) &= 14n+2i-1\\
f_2(a_ib_i) &= 8n+2i-1\\
f_2(A_iA_{(i+1)modn}) &= 4n+2i-1\\
f_2(B_iB_{(i+1)modn}) &= 12n-2i+1\\
f_2(A_iB_{(i+1)modn}) &= 18n+2i-1\\
f_2(A_iB_i) &= 14n-2i+1\\
f_2(a_iA_i) &= 4n-2i+1\\
f_2(b_iB_i) &= 16n+2i-1
\end{aligned}
$$

for all $i = 1, 2, \ldots, n$. It is clear that

$$
\begin{aligned}
\{f_2(a_ia_{(i+1)modn})|i=1,2,\ldots,n\} &= \{1,3,\ldots,2n-1\}\\
\{f_2(b_ib_{(i+1)modn})|i=1,2,\ldots,n\} &= \{6n+1,6n+3,\ldots,8n-1\}\\
\{f_2(a_ib_{(i+1)modn})|i=1,2,\ldots,n\} &= \{14n+1,14n+3,\ldots,16n-1\}\\
\{f_2(a_ib_i)|i=1,2,\ldots,n\} &= \{8n+1,8n+3,\ldots,10n-1\}\\
\{f_2(A_iA_{(i+1)modn})|i=1,2,\ldots,n\} &= \{4n+1,4n+3,\ldots,6n-1\}\\
\{f_2(B_iB_{(i+1)modn})|i=1,2,\ldots,n\} &= \{10n+1,10n+3,\ldots,12n-1\}\\
\{f_2(A_iB_{(i+1)modn})|i=1,2,\ldots,n\} &= \{18n+1,18n+3,\ldots,20n-1\}\\
\{f_2(A_iB_i)|i=1,2,\ldots,n\} &= \{12n+1,12n+3,\ldots,14n-1\}\\
\{f_2(a_iA_i)|i=1,2,\ldots,n\} &= \{2n+1,2n+3,\ldots,4n-1\}\\
\{f_2(b_iB_i)|i=1,2,\ldots,n\} &= \{16n+1,16n+3,\ldots,18n-1\}
\end{aligned}
$$

confirming that $f_2$ is a bijection. Furthermore we then obtain the following vertex weights $mod\ 2k$ for $2k = 20n$ under the labeling $f_2$:

$$
\begin{aligned}
&wt_{f_3}(a_1) = 8n+1\\
&wt_{f_3}(a_i) = 10n-2i+3 && \text{for } i = 2,3,\ldots,n\\
&wt_{f_3}(b_1) = 14n+1\\
&wt_{f_3}(b_i) = 14n+2i-1 && \text{for } i = 2,2,\ldots,n\\
&wt_{f_3}(A_1) = 6n-1\\
&wt_{f_3}(A_i) = 4n+2i-3 && \text{for } i = 2,3,\ldots,n\\
&wt_{f_3}(B_1) = 12n-1\\
&wt_{f_3}(B_i) = 12n-2i+1 && \text{for } i = 2,3,\ldots,n.
\end{aligned}
$$

It is easy to check that

$$
\begin{aligned}
\{wt_{f_3}(a_1)\} &= \{8n+1\}\\
\{wt_{f_3}(a_i)|i=2,3,\ldots,n\} &= \{8n+3, 8n+5, \ldots, 10n-1\}\\
\{wt_{f_3}(b_1)\} &= \{14n+1\}\\
\{wt_{f_3}(b_i)|i=2,3,\ldots,n\} &= \{14n+3, 14n+5, \ldots 16n-1\}\\
\{wt_{f_3}(A_1)\} &= 6n-1\\
\{wt_{f_3}(A_i)|i=2,3,\ldots,n\} &= \{4n+1, 4n+3, \ldots, 6n-3\}\\
\{wt_{f_3}(B_1)\} &= 12n-1\\
\{wt_{f_3}(B_i)|i=2,3,\ldots,n\} &= \{10n+1, 10n+3, \ldots, 12n-3\}
\end{aligned}
$$

showing that the weights are all distinct. Hence $f_2$ is an edge odd graceful on $P_2 \times A_n$ and therefore $P_2 \times A_n$ is an edge oddd graceful. □

In Figure 7., we give an illustration of an edge odd labeling on $P_2 \times A_8$. We separate the graph into several part to make the labeling look clear.

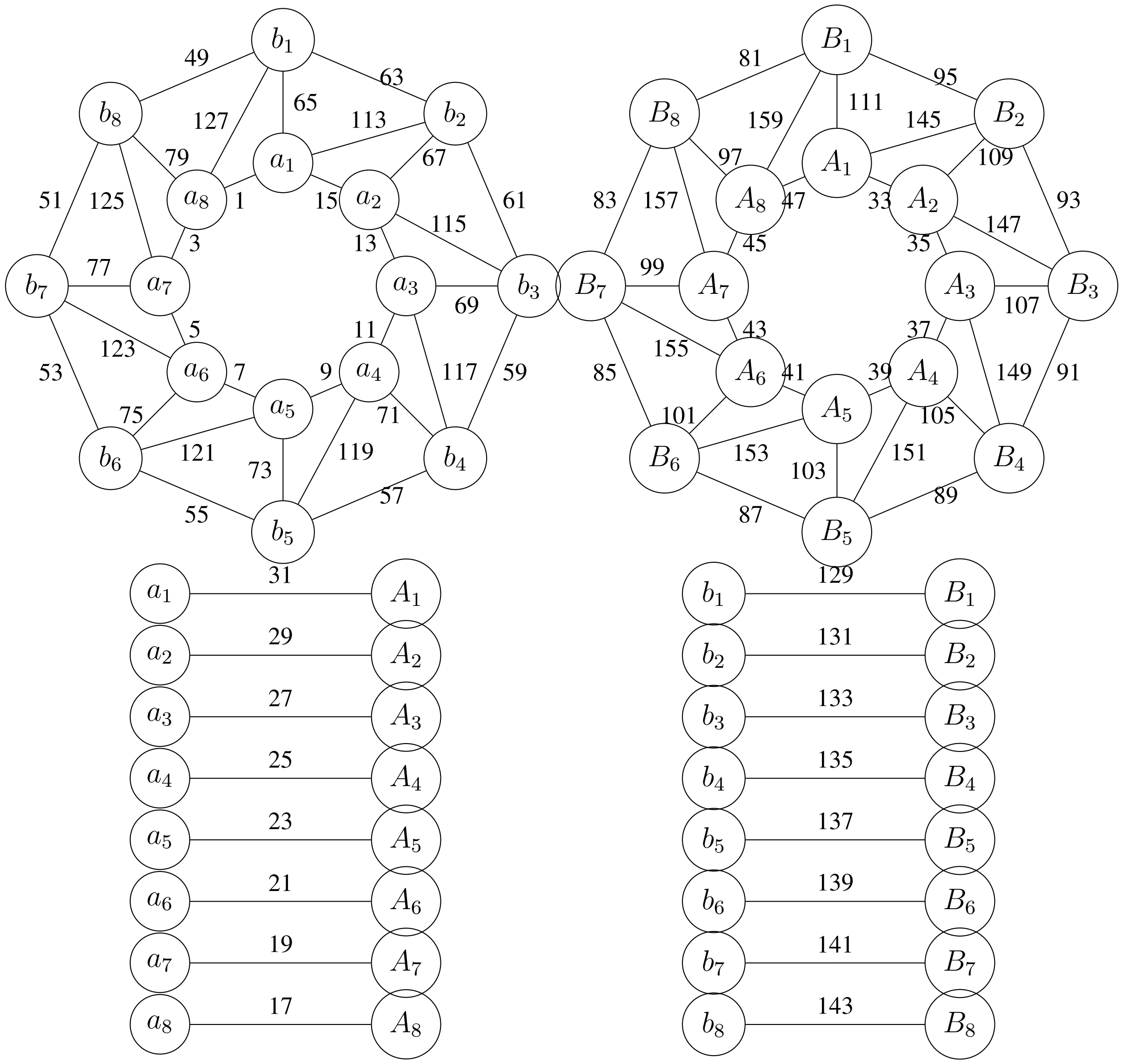


**Figure 7.** Edge Odd Graceful Labeling on Cartesian Product $P_2 \times A_8$

From the Figure 7., we obtain vertex weights $mod$ 160 respect to labeling $f_2$ as follows:

$$\begin{array}{llll}
wt_{f_3}(a_1) = 65 & wt_{f_3}(b_1) = 113 & wt_{f_3}(A_1) = 47 & wt_{f_3}(B_1) = 95 \\
wt_{f_3}(a_2) = 79 & wt_{f_3}(b_2) = 115 & wt_{f_3}(A_2) = 33 & wt_{f_3}(B_2) = 93 \\
wt_{f_3}(a_3) = 77 & wt_{f_3}(b_3) = 117 & wt_{f_3}(A_3) = 35 & wt_{f_3}(B_3) = 91 \\
wt_{f_3}(a_4) = 75 & wt_{f_3}(b_4) = 119 & wt_{f_3}(A_4) = 37 & wt_{f_3}(B_4) = 89 \\
wt_{f_3}(a_5) = 73 & wt_{f_3}(b_5) = 121 & wt_{f_3}(A_5) = 39 & wt_{f_3}(B_5) = 87 \\
wt_{f_3}(a_6) = 71 & wt_{f_3}(b_6) = 123 & wt_{f_3}(A_6) = 41 & wt_{f_3}(B_6) = 85 \\
wt_{f_3}(a_7) = 69 & wt_{f_3}(b_7) = 125 & wt_{f_3}(A_7) = 43 & wt_{f_3}(B_7) = 83 \\
wt_{f_3}(a_8) = 67 & wt_{f_3}(b_8) = 127 & wt_{f_3}(A_8) = 45 & wt_{f_3}(B_8) = 81.
\end{array}$$

### 3.3. Cartesian Product of Path $P_2$ and Double Sun Flower $DSF_n$

**Definition 1** *A sun flower graph of order* $2n$*, denoted by* $SF_n$*, is a graph that is isomorphic to a graph obtained by deleting edges of the outer cycle from antiprism graph* $A_n$ *(see FIGURE 8.).*

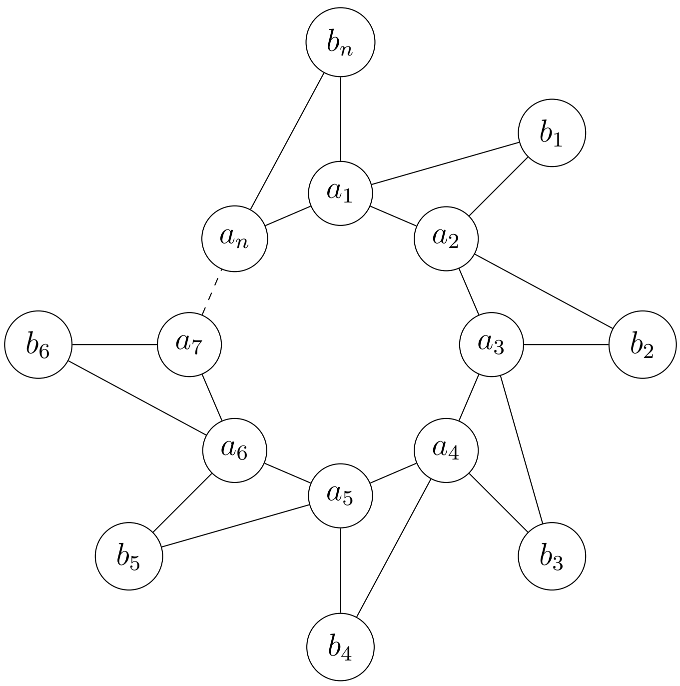


**Figure 8.** Sun Flower Graph $SF_n$

The vertex set and the edge set of $SF_n$ of order $2n$, are, respectively

$$V(SF_n) = \{a_i, b_i | i = 1, 2, \ldots, n\}$$

and

$$E(SF_n) = \{a_i a_{(i+1) mod\ n}, a_i b_i, a_{(i+1) mod\ n} b_i | i = 1, 2, \ldots, n\}.$$

Thus we have $|V(SF_n)| = 2n$ and $|E(SF_n)| = 3n$.

**Definition 2** *By a double sun flower graph of order $3n$, denoted by $DSF_n$, is a graph obtained from the graph $SF_n$ (see FIGURE 8.) by inserting a new vertex $c_i$ on each edges $a_ia_{i+1}$ and adding edges $b_ic_i$ for each $i$. (See FIGURE 9.)*

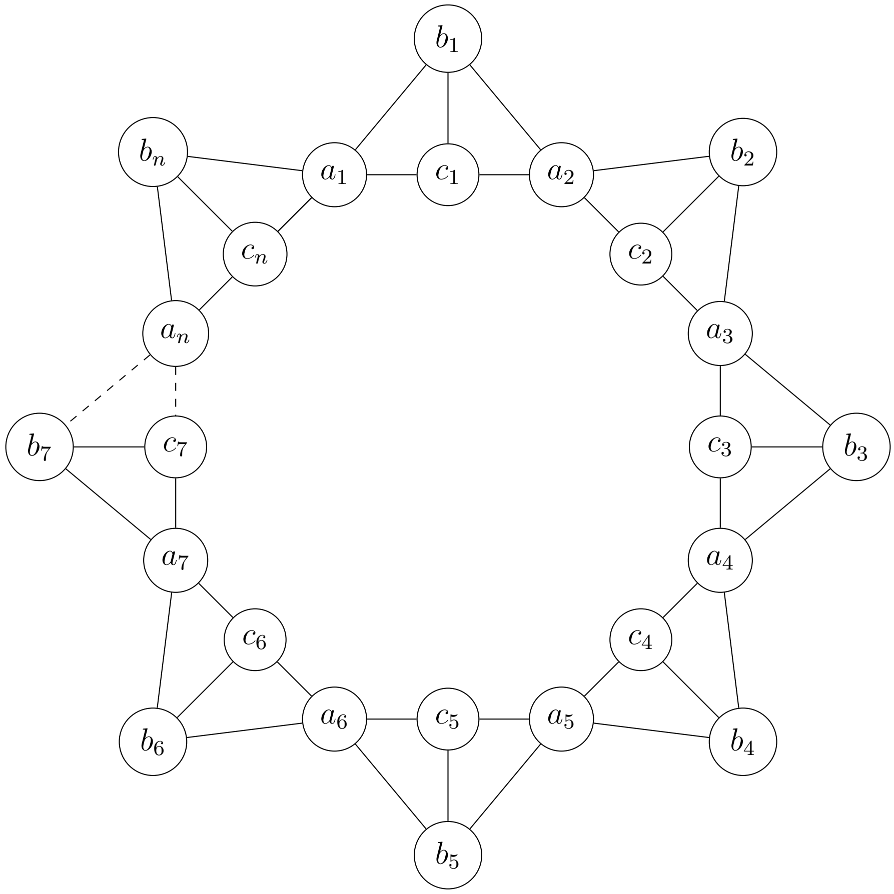


**Figure 9.** Double Sun Flower Graph $DSF_n$

**Theorem 3** *Let $n \geq 3$ be an arbitrary positive integer. Then the graph $P_2 \times DSF_n$ is edge odd graceful.*

*Proof.* Let the vertex set and the edge set of $P_2 \times DSF_n$ be

$$V(P_2 \times DSF_n) = \{a_i, b_i, c_i, A_i, B_i, C_i | i = 1, 2, \dots, n\}$$

and

$$E(P_2 \times DSF_n) = \{a_ib_i, a_ic_i, b_ic_i, b_ia_{(i+1)modn}, c_ia_{(i+1)modn} | i = 1, 2, \dots, n\} \cup$$

$$\{A_iB_i, A_iC_i, B_iC_i | i = 1, 2, \dots, n\} \cup$$

$$\{B_iA_{(i+1)modn}, C_iA_{(i+1)modn}, a_iA_i, b_iB_i, c_iC_i | i = 1, 2, \dots, n\}.$$

It is clear that

$$|V(P_2 \times DSF_n)| = 6n$$

and

$$|E(P_2 \times DSF_n)| = 13n.$$

We construct an edge labeling $f_3 : E(P_2 \times DSF_n) \to \{1, 3, \ldots, 26n-1\}$ for two cases, whenever $n$ is odd and $n$ is even.

**Case for $n$ odd**

We define the labeling as follows:

$$\begin{aligned}
f_3(a_ib_i) &= 20n - 2i + 1\\
f_3(a_ic_i) &= 16n - 2i + 1\\
f_3(b_ic_i) &= 12n + 2i - 1\\
f_3(b_ia_{(i+1)modn}) &= 10n + 2i - 1\\
f_3(c_ia_{(i+1)modn}) &= 18n - 2i + 1\\
f_3(A_iB_i) &= 10n - 2i + 1\\
f_3(A_iC_i) &= 6n - 2i + 1\\
f_3(B_iC_i) &= 22n + 2i - 1\\
f_3(B_iA_{(i+1)modn}) &= 2i - 1\\
f_3(C_iA_{(i+1)modn}) &= 8n - 2i + 1\\
f_3(a_iA_i) &= 20n + 2i - 1\\
f_3(b_iB_i) &= 2n + 2i - 1\\
f_3(c_iC_i) &= 26n - 2i + 1
\end{aligned}$$

for all $i = 1, 2, \ldots, n$. It is easy to see that

$$\begin{aligned}
\{f_3(a_ib_i)|i = 1, 2, \ldots, n\} &= \{18n + 1, 18n + 3, \ldots, 20n - 1\}\\
\{f_3(a_ic_i)|i = 1, 2, \ldots, n\} &= \{14n + 1, 14n + 3, \ldots, 16n - 1\}\\
\{f_3(b_ic_i)|i = 1, 2, \ldots, n\} &= \{12n + 1, 12n + 3, \ldots, 14n - 1\}\\
\{f_3(b_ia_{(i+1)modn})|i = 1, 2, \ldots, n\} &= \{10n + 1, 10n + 3, \ldots, 12n - 1\}\\
\{f_3(c_ia_{(i+1)modn})|i = 1, 2, \ldots, n\} &= \{16n + 1, 16n + 3, \ldots, 18n - 1\}\\
\{f_3(A_iB_i)|i = 1, 2, \ldots, n\} &= \{8n + 1, 8n + 3, \ldots, 10n - 1\}\\
\{f_3(A_iC_i)|i = 1, 2, \ldots, n\} &= \{4n + 1, 4n + 3, \ldots, 6n - 1\}\\
\{f_3(B_iC_i)|i = 1, 2, \ldots, n\} &= \{22n + 1, 22n + 3, \ldots, 24n - 1\}\\
\{f_3(B_iA_{(i+1)modn})|i = 1, 2, \ldots, n\} &= \{1, 3, \ldots, 2n - 1\}\\
\{f_3(C_iA_{(i+1)modn})|i = 1, 2, \ldots, n\} &= \{6n + 1, 6n + 3, \ldots, 8n - 1\}\\
\{f_3(a_iA_i)|i = 1, 2, \ldots, n\} &= \{20n + 1, 20n + 3, \ldots, 22n - 1\}\\
\{f_3(b_iB_i)|i = 1, 2, \ldots, n\} &= \{2n + 1, 2n + 3, \ldots, 4n - 1\}\\
\{f_3(c_iC_i)|i = 1, 2, \ldots, n\} &= \{24n + 1, 24n + 3, \ldots, 26n - 1\}.
\end{aligned}$$

Thus $f_3$ is a bijection. Moreover, we then have vertex weights $mod2k$, where $k = max\{|V(P_2\times DSF_n)|, |E(P_2 \times DSF_n)|\} = max\{5n, 13n\} = 13n$ as follows:

$$\begin{array}{lll} wt_{f_3}(a_1) = 6n-1 & wt_{f_3}(A_1) = 18n-1 & \\ wt_{f_3}(a_i) = 6n-2i+1 & wt_{f_3}(A_i) = 18n-2i+1 & \text{for } i = 2,3,\ldots,n \\ wt_{f_3}(b_i) = 18n+4i-2 & wt_{f_3}(B_i) = 8n+4i-2 & \text{for } i = 1,2,\ldots,n \\ wt_{f_3}(c_i) = 20n-4i+2 & wt_{f_3}(C_i) = 10n-4i+2 & \text{for } i = 1,2,\ldots,n \end{array}$$

so that

$$\begin{array}{lll} \{wt_{f_3}(a_1)\} & = & \{6n-1\} \\ \{wt_{f_3}(a_i)|i=2,3,\ldots,n\} & = & \{4n+1, 4n+3, \ldots, 6n-3\} \\ \{wt_{f_3}(b_i)|i=1,2,\ldots,n\} & = & \{18n+2, 18n+6, \ldots, 22n-1\} \\ \{wt_{f_3}(c_i)|i=1,2,\ldots,n\} & = & \{16n+2, 16n+6, \ldots, 20n-2\} \\ \{wt_{f_3}(A_1)\} & = & \{18n-1\} \\ \{wt_{f_3}(A_i)|i=2,3,\ldots,n\} & = & \{16n+1, 16n+3, \ldots, 18n-3\} \\ \{wt_{f_3}(B_i)|i=1,2,\ldots,n\} & = & \{8n+2, 8n+6, \ldots, 12n-2\} \\ \{wt_{f_3}(C_i)|i=1,2,\ldots,n\} & = & \{6n+2, n+6, \ldots, 10n-2\}. \end{array}$$

It is easy to check that for arbitrary odd number $n \geq 3$, all the weights are different. Therefore $f_3$ is an edge odd graceful labeling. Thus, for $n \geq 3$ odd, $P_2 \times DSF_n$ is edge odd graceful.

**Case for $n$ even**

For $n \geq 3$ even we define the labeling as follows:

$$\begin{array}{lll} f_3(a_ib_i) & = & 16n-2i+1 \\ f_3(a_ic_i) & = & 20n-2i+1 \\ f_3(b_ic_i) & = & 2i-1 \\ f_3(b_ia_{(i+1)modn}) & = & 10n+2i-1 \\ f_3(c_ia_{(i+1)modn}) & = & 16n-2i+1 \\ f_3(A_iB_i) & = & 8n-2i+1 \\ f_3(A_iC_i) & = & 10n-2i+1 \\ f_3(B_iC_i) & = & 12n+2i-1 \\ f_3(B_iA_{(i+1)modn}) & = & 22n+2i-1 \\ f_3(C_iA_{(i+1)modn}) & = & 18n-2i+1 \\ f_3(a_iA_i) & = & 20n+2i-1 \\ f_3(b_iB_i) & = & 2n+2i-1 \\ f_3(c_iC_i) & = & 26n-2i+1 \end{array}$$

for all $i = 1, 2, \ldots, n$. We obtain

$$\begin{aligned}
\{f_3(a_ib_i)|i=1,2,\ldots,n\} &= \{14n-1,14n+1,\ldots,16n-1\}\\
\{f_3(a_ic_i)|i=1,2,\ldots,n\} &= \{18n+1,18n+3,\ldots,20n-1\}\\
\{f_3(b_ic_i)|i=1,2,\ldots,n\} &= \{1,3,\ldots,2n-1\}\\
\{f_3(b_ia_{(i+1)modn})|i=1,2,\ldots,n\} &= \{10n+1,10n+3,\ldots,12n-1\}\\
\{f_3(c_ia_{(i+1)modn})|i=1,2,\ldots,n\} &= \{14n+1,14n+3,\ldots,16n-1\}\\
\{f_3(A_iB_i)|i=1,2,\ldots,n\} &= \{6n+1,6n+3,\ldots,8n-1\}\\
\{f_3(A_iC_i)|i=1,2,\ldots,n\} &= \{8n+1,8n+3,\ldots,10n-1\}\\
\{f_3(B_iC_i)|i=1,2,\ldots,n\} &= \{12n+1,12n+3,\ldots,14n-1\}\\
\{f_3(B_iA_{(i+1)modn})|i=1,2,\ldots,n\} &= \{22n+1,22n+3,\ldots,24n-1\}\\
\{f_3(C_iA_{(i+1)modn})|i=1,2,\ldots,n\} &= \{16n+1,16n+3,\ldots,18n-1\}\\
\{f_3(a_iA_i)|i=1,2,\ldots,n\} &= \{20n+1,20n+3,\ldots,22n-1\}\\
\{f_3(b_iB_i)|i=1,2,\ldots,n\} &= \{2n+1,2n+3,\ldots,4n-1\}\\
\{f_3(c_iC_i)|i=1,2,\ldots,n\} &= \{24n+1,24n+3,\ldots,26n-1\}.
\end{aligned}$$

We then have vertex weights $mod2k$, where $k = max\{|V(P_2 \times DSF_n)|, |E(P_2 \times DSF_n)|\} = max\{5n, 13n\} = 13n$ as follows:

$$\begin{aligned}
&wt_{f_3}(a_1) = 20n-1 &&\\
&wt_{f_3}(a_i) = 20n-2i+1 && \text{for } i=2,3,\ldots,n\\
&wt_{f_3}(b_i) = 2n+4i-2 && \text{for } i=1,2,\ldots,n\\
&wt_{f_3}(c_i) = 26n-4i+2 && \text{for } i=1,2,\ldots,n.\\
&wt_{f_3}(A_1) = 26n-1 &&\\
&wt_{f_3}(A_i) = 26n-2i+1 && \text{for } i=2,3,\ldots,n\\
&wt_{f_3}(B_i) = 18n+4i-2 && \text{for } i=1,2,\ldots,n\\
&wt_{f_3}(C_i) = 14n-4i+2 && \text{for } i=1,2,\ldots,n.
\end{aligned}$$

Clearly,

$$\begin{aligned}
\{wt_{f_3}(a_1)\} &= \{20n-1\}\\
\{wt_{f_3}(a_i)|i=2,3,\ldots,n\} &= \{18n+1,18n+3,\ldots,20n-3\}\\
\{wt_{f_3}(b_i)|i=1,2,\ldots,n\} &= \{2n+2,2n+6,\ldots,6n-2\}\\
\{wt_{f_3}(c_i)|i=1,2,\ldots,n\}\} &= \{22n+2,22n+6,\ldots,26n-2\}.\\
\{wt_{f_3}(A_1)\} &= \{26n-1\}\\
\{wt_{f_3}(A_i)|i=2,3,\ldots,n\} &= \{24n+1,24n+3,\ldots,26n-3\}\\
\{wt_{f_3}(B_i)|i=1,2,\ldots,n\} &= \{18n+2,18n+6,\ldots,22n-2\}\\
\{wt_{f_3}(C_i)|i=1,2,\ldots,n\} &= \{10n+2,10n+6,\ldots,14n-2\}.
\end{aligned}$$

Therefore $f_3$ is an edge odd labeling for every even number $n \geq 3$ and hence $P_2 \times DSF_n$ is edge odd graceful for each even positive integer $n \geq 3$ . Thus $P_2 \times DSF_n$ is edge odd graceful for arbitrary positive integer $n \geq 3$. □

Figure 10. shows an edge odd labeling on $P_2 \times DSF_3$. To make the figure look clear, we

draw the graph into several separate parts. Respect to the labeling $f_3$ for $P_2 \times DSF_3$ we have

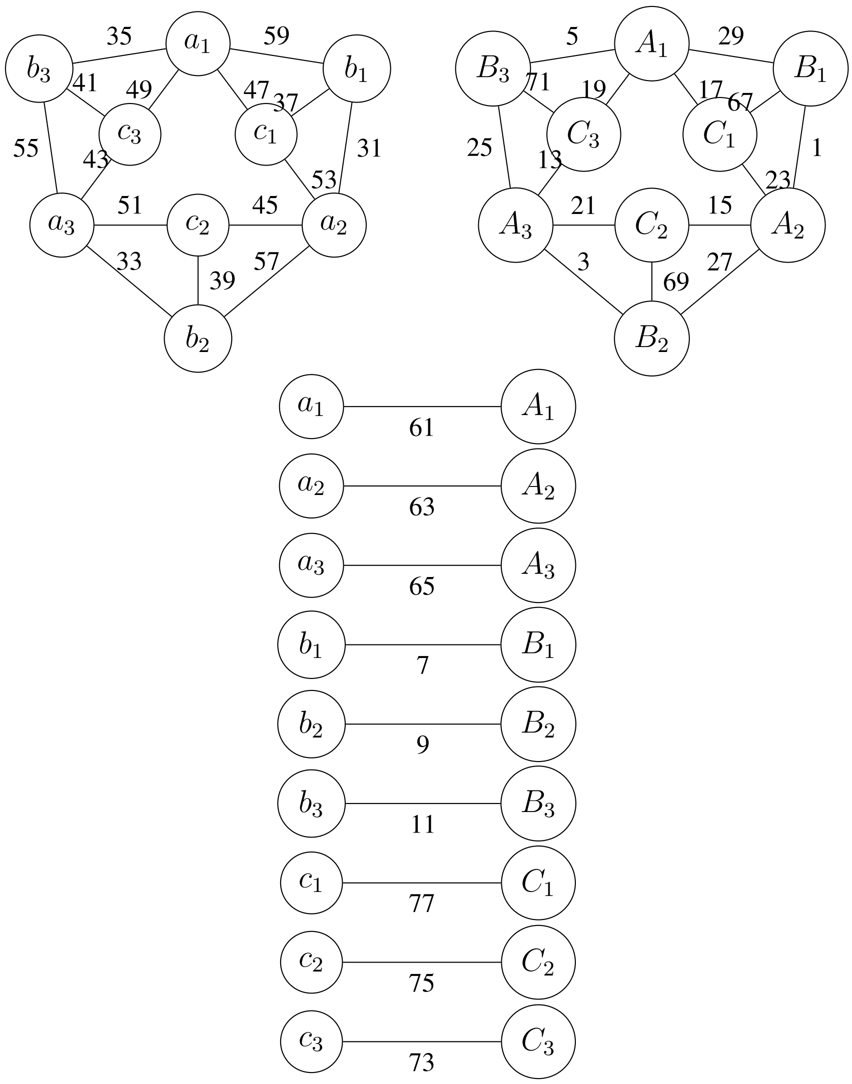


**Figure 10.** Edge Odd Graceful Labeling $f_3$ for $P_2 \times DSF_3$

the following vertex weights:

$$
\begin{aligned}
&wt_{f_2}(a_1) = 17 && wt_{f_2}(A_1) = 53\\
&wt_{f_2}(a_2) = 15 && wt_{f_2}(A_2) = 51\\
&wt_{f_2}(a_3) = 13 && wt_{f_2}(A_3) = 49\\
&wt_{f_2}(b_1) = 56 && wt_{f_2}(B_1) = 26\\
&wt_{f_2}(b_2) = 60 && wt_{f_2}(B_2) = 30\\
&wt_{f_2}(b_3) = 64 && wt_{f_2}(B_3) = 34\\
&wt_{f_2}(c_1) = 58 && wt_{f_2}(C_1) = 28\\
&wt_{f_2}(c_2) = 54 && wt_{f_2}(C_2) = 24\\
&wt_{f_2}(c_3) = 50 && wt_{f_2}(C_3) = 20.
\end{aligned}
$$

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