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Cordial and Mean Labelings on Extended Duplicate Graph of Comb Graph

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Authors' contributions

This work was carried out in collaboration between all authors. Author KT designed the study and supervised the work. Author KS wrote the first draft of the manuscript and managed literature searches. Authors KS, KT and SB managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A graph labeling is a mapping that carries a set of graph elements onto a set of numbers called labels (usually the set of integers). In this paper we prove the existence of graph labeling such as cordial, total cordial, product cordial, total product cordial, prime cordial, odd mean labeling and even mean labeling for extended duplicate graph of Comb graph by presenting algorithms.

Keywords: Graph labeling; comb; duplicate graph.

AMS subject classification: 05C78.

1. INTRODUCTION

Graph labeling has the origin from a seminal paper by Rosa in [1] and established by Gallian [2]. It is defined as an assignment of integers to the vertices or edges or both subject to certain conditions. The notion of cordial labeling was introduced by Cahit [3]. A function

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$f : V \to \{0,1\}$ is said to be cordial labeling if each edge *uv* receives the label $|f(u) - f(v)|$ such that the number of vertices labeled with '0' and the number of vertices labeled with '1' differ by at most one, and the number of edges labeled with '0' and the number of edges labeled with '1' differ by at most one. Moreover, it admits total cordial labeling if the number of vertices and edges labeled with '0' and the number of vertices and edges labeled with '1'differ by at most one.

Andar et al. [4] proved that a cordial labeling of G can be extended to a cordial labeling of the graph obtained from G by attaching 2 m pendent edges at each vertex of G.

The concept of product, total product and prime cordial labeling was introduced by Sundaram et al. [5]. A function $f: V \to \{0,1\}$ such that each edge *uv* receives the label $f(u)\times f(v)$ is said to be product cordial labeling if the number of vertices labeled with '0' and the number of vertices labeled with '1' differ by at most one, and the number of edges labeled with '0' and the number of edges labeled with '1'differ by at most one. Moreover, it is said to be total product cordial labeling if the number of vertices and edges labeled with '0' and the number of vertices and edges labeled with '1' differ by at most one.

Basker Babujee et al. [6] study the concept of prime cordial labeling. In [7] Bondy and Murthy established many applications in graph theory.

A prime cordial labeling of a graph G with vertex set V is a function $f : V \to \{1, 2, 3, ..., p\}$ such that the induced function $f^* : E \to N$ is defined by $f^*(v_iv_j)$ is assigned the label 1, if $\gcd(f(v_i), f(v_j)) = 1$ and 0, if $\gcd(f(v_i), f(v_j)) > 1$, then the number of edges labeled with '0' and '1' differ by atmost 1. It was proved that the graphs C_n if and only if $n \geq 6$: P_n if and only if $n \neq 3$ or 5; bistars; dragons; crowns; ladders are prime cordial.

Nirmala investigated the concept of odd and even mean labeling.A function *f* is called an odd mean labeling of a graph G if there exists an injective function $f : V \to \{1,3,5,\ldots,2q-1\}$ such that when each edge v_iv_j receives a label $(f(v_i)+f(v_j))/2$, then the resulting edge labels are distinct. A graph which admits an odd mean labeling is called an odd mean graph. A function f is called an even mean labeling of a graph G if there exists an injective function $f : V \to \{2,4,\ldots,2q\}$ such that when each edge v_iv_j receives a label $(f(v_i) + f(v_j))/2$ then the resulting edge labels are distinct. A graph which admits an even mean labeling is called an even mean graph.

Thirusangu et al. [8,9] have introduced the concept of extended duplicate graph. A Duplicate graph of a path graph G(V,E) is $DG=(V_1,E_1)$ where the vertex set $V_1 = V\cup V'$ and $V\cap V'=\Phi$ and $f: V\to V'$ is bijective (for $v \in V$, we write $f(v) = v'$ for convenience) and the edge set E_1 of DG is defined as follows: The edge v_iv_j is in E if and only if both v_iv_j' and $v_i'v_j$ are edges in E_1. Clearly duplicate graph is disconnected. In order to make it as connected, add an edge v_iv_i' for any `i'. This graph is called the Extended Duplicate Graph of a path graph G.

It was shown that the extended duplicate graph of a path P_m admits cordial ,total cordial, product cordial and total product cordial labeling.

Singh et al, [10] proved some results on Comb graph. Let P_{m+1} be a path graph.Comb graph is defined as $P_{m+1}\odot (m+1)K_1$. It has 2m+2 vertices and 2 m+1 edges.

In this paper, we prove that, the extended duplicate graph of Comb graph is cordial, total cordial, product cordial, total product cordial, prime cordial, odd mean and even mean labeling by presenting algorithms.

2. MAIN RESULTS

In this section we present the structure of the extended duplicate graph of a comb graph and establish the existence of cordial, total cordial, product cordial, total product cordial, prime cordial, odd and even mean labeling for the extended duplicate graph of Comb graph by presenting algorithms.

Definition: (Structure of the extended duplicate graph of a comb graph)

Let G(V,E) be a comb graph. DG(comb)= (V_1,E_1) is the duplicate graph of comb graph with 4m+4 vertices and 4m+2 edges.

Denote the vertex set as $V_1=\{v_1,v_2,\ldots v_{2m+2},v_1',v_2'\ldots v_{2m+2}'\}$ and the edge set as $E_1=\{v_iv_{i+1}' \cup v_i'v_{i+1}$ for $1 \leq i \leq m) \cup (v_i'v_{m+i+1} \cup v_iv_{m+i+1}'$ for $1 \leq i \leq m+1)\}$. Clearly DG(comb) is disconnected. The extended duplicate graph of a comb EDG(Comb) is obtained from DG(comb) by adding the edges (i) v_1v_{m+1} and $v_{m+2}'v_{2m+2}'$ if $m \equiv 1 (\mathrm{mod}\ 2)$ (ii) v_1v_{m+1}' and $v_{m+2}'v_{2m+2}$ if $m \equiv 0 (\mathrm{mod}\ 2)$.

Thus the extended duplicate graph of comb graph has 4m+4 vertices and 4m+4 edges.

Algorithm2.1

Procedure (cordial labeling for extended duplicate graph of comb graph)
V = $\{v_1, v_2 \ldots\ldots v_{2m+2}, v_1', v_2' \ldots\ldots v_{2m+2}'\}$
// assignment of labels to vertices
If m = 2n
for i = 1 to m+1 do
{ v_i, v_{m+i+1}' ← 0
v_i', v_{m+i+1} ← 1
}
end for
If m = 2n+1
for i = 1 to 2m+2 do
{v_i , v_i' = 0 if i ≡ 0 (mod 2)
1 otherwise
}
end for
end procedure
output: vertex labeled extended duplicate graph of comb graph.

Theorem 2.1

The extended duplicate graph of comb graph is cordial.

Proof:

From the construction of extended duplicate graph of comb graph , it is clear that EDG(comb) (V,E) graph has 4m+4 vertices and 4m+4 edges.

In order to label the vertices, define a function $f : V \rightarrow \{0, 1\}$ as given in algorithm 2.1.

Clearly,

The number of vertices labeled with ‘0’ = m+1 +m+1 =2m+2
The number of vertices labeled with ‘1’ = m+1 +m+1 =2m+2

Thus the number of vertices labeled with ‘0’ and ‘1’ is differ by atmost ‘1’.

In order to get the edge labels, define the induced map $f^* : E \rightarrow N$ such that

$f^*(v_iv_j) = [f(v_i) + f(v_j)] \pmod 2$.The edge labels are obtained as follows:

For $1 \le i \le m$
$f^*(v_iv_{i+1}') = f^*(v_i'v_{i+1}) = 1$, $f^*(v_iv_{m+i+1}') = f^*(v_i'v_{m+i+1}) = 0$
If m = 2n
$f^*(v_1v_{m+1}') = f^*(v_{m+2}'v_{2m+2}) = 1$, $f^*(v_1v_{m+2}') = f^*(v_{m+1}'v_{2m+2}) = 0$
If m = 2n + 1
$f^*(v_1v_{m+1}) = f^*(v_{m+2}'v_{2m+2}') = 1$, $f^*(v_{m+1}v_{2m+2}') = f^*(v_{m+1}'v_{2m+2}) = 0$

Thus the number of edges labeled with ‘0’ = m+m+2 = 2 m+2

The number of edges labeled with ‘1’ = m+m+2 = 2 m+2
Hence the number of edges labeled with ‘0’ and ‘1’ differ by atmost one.

Therefore EDG (comb) graph is cordial.

Theorem 2.2

The extended duplicate graph of comb graph EDG (comb), $m \geq 2$ is total cordial.

Proof :

By theorem 2.1, the number of vertices labeled with '1' and '0' are same as 2 m + 2. The number of edges labeled with '1' and '0' are same as 2 m + 2. Thus the total number of vertices and edges labeled with '1' is 4 m+4 and the total number of vertices and edges labeled with '0' is 4 m+4. Clearly the total number of vertices and edges labeled with '1' and the total number of vertices and edges labeled with '0' differ by atmost one.

Hence the extended duplicate graph of comb graph is total cordial.

Example 2.1

Cordial labeling of EDG (comb)for m=5 and m=6 are given in Figs. 1 and 2 respectively.

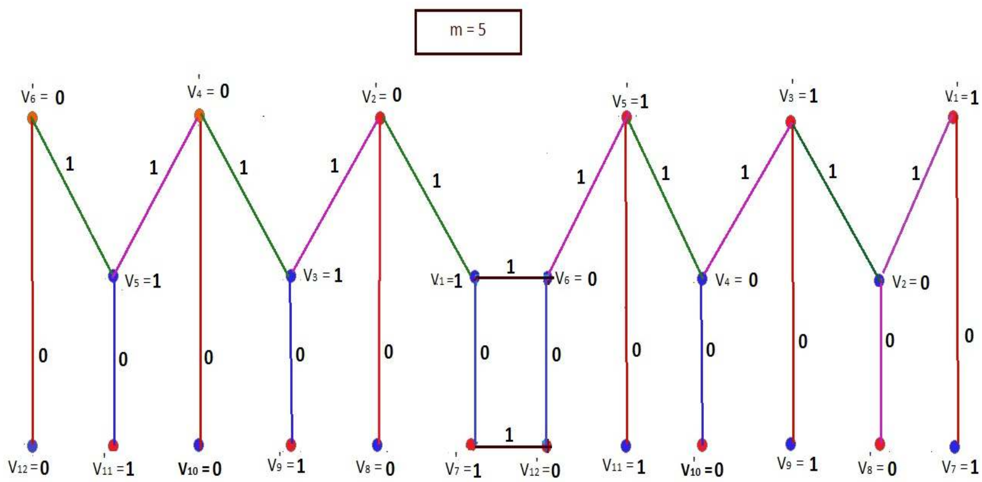

Fig. 1. Cordial labeling of EDG(comb) graph for m = 5

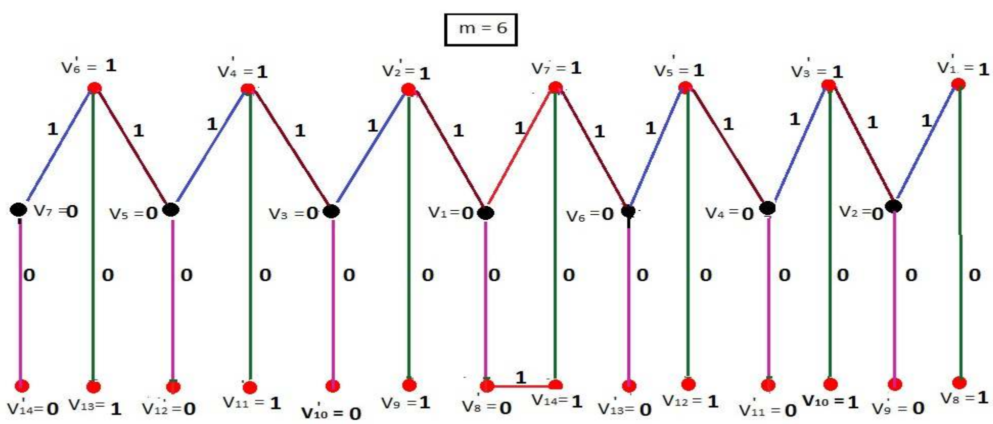

Fig. 2. Cordial labeling of EDG(comb) graph for m = 6

Algorithm 2.2

Procedure: (Product cordial labeling for extended duplicate graph of comb graph)
V = {v_1 , v_2 . . . . . v_{2m+2} , v_1', v_2'. . . . . v_{2m+2}'}
// assignment of labels to vertices
v_1', v_2 ← 0 ; v_1 , v_{m+2}' ← 1
for i = 3 to m+1 do
{ v_i ← 1
}
end for
for i = 2 to m+1 do
{ v_i' ← 1
}
end for
for i = 1 to m do
{ v_{m+i+1} ← 0
}
end for
for i = 2 to m do
{ v_{m+i+1}' ← 0
}
end for
if m = 2n
v_{2m+2} ← 1 : v_{2m+2}' ← 0
if m = 2n+1
v_{2m+2} ← 0 : v_{2m+2}' ← 1
end for
end procedure
output: vertex labeled extended duplicate graph of comb graph.

Theorem 2.3

The extended duplicate graph of comb graph EDG (comb), $m \geq 2$ is product cordial.

Proof:

Clearly, EDG (comb) (V,E) has 4m + 4 vertices and 4 m + 4 edges. In order to label the vertices, define a function $f : V \rightarrow \{0 , 1\}$, using algorithm 2.2.

It is evident that the number of vertices labeled with ‘0’ = 2+m-1+m+1 = 2 m+2.

Number of vertices labeled with ‘1’ = 2+m-1+m+1 = 2 m+2.

Hence the number of vertices labeled with ‘0’ and ‘1’ differ by atmost one. In order to get the edge labels, define the induced map $f^* : E \rightarrow N$ such that $f^*[v_iv_j] = [f(v_i) \times f(v_j)]$.

Thus the edge labels are obtained as follows:

$f^*(v_1v_2') = f^*(v_1v_{m+2}') = 1$: $f^*(v_1'v_2) = f^*(v_2v_3') = 0$
For $1 \leq i \leq m$
$f^*(v_i'v_{m+i+1}) = 0$
For $2 \leq i \leq m$
$f^*(v_i'v_{i+1}) = 1$: $f^*(v_iv_{m+i+1}') = 0$
For $3 \leq i \leq m$ **;** $f^*(v_iv_{i+1}') = 1$

If $m = 2n$
$f^*(v_{m+1}v_{2m+2}') = 0$, $f^*(v_1v_{m+1}') = f^*(v_{m+1}'v_{2m+2}) = f^*(v_{m+2}'v_{2m+2}) = 1$
If $m = 2n + 1$
$f^*(v_{m+1}'v_{2m+2}) = 0$, $f^*(v_1v_{m+1}) = f^*(v_{m+1}v_{2m+2}') = f^*(v_{m+2}'v_{2m+2}') = 1$

Thus the number of edges labeled with ‘0’ = 2+m+m-1+1 = 2 m+2.

Number of edges labeled with ‘1’ = 2+m-1+m-2 + 3 = 2 m+2.

Hence the number of edges labeled with ‘0’ and ‘1’ differ by atmost one.

Therefore EDG (comb) graph is product cordial.

Theorem 2.4:

The extended duplicate graph of comb graph, EDG (comb) $m \geq 2$ is total product cordial.

Proof:

By theorem 2.3, the number of vertices labeled with ‘0’ and ‘1’ are same as 2 m+ 2. The number of edges labeled with ‘0’ and ‘1’ are same as 2m+2. Thus the total number of vertices and edges labeled with ‘0’ is 4m + 4 and the total number of vertices and edges labeled with ‘1’ is 4 m + 4. Hence the total number of vertices and edges labeled with ‘0’ and ‘1’ differ by atmost one.

Therefore EDG (comb) graph is total product cordial.

Example 2.2

Product cordial labeling of EDG (comb) graph for m =5 and m=6 are given in Figs. 3 and 4 respectively.

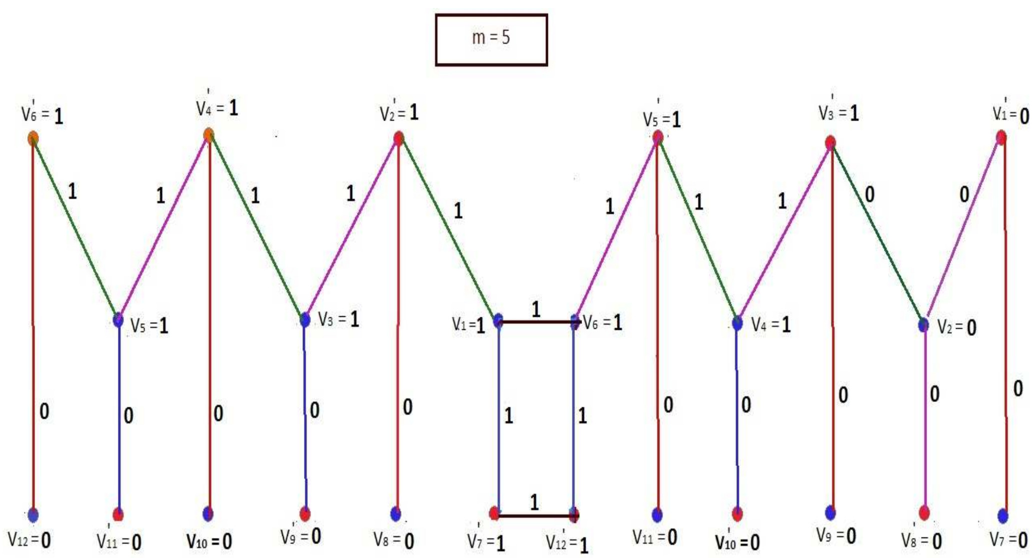

Fig. 3. Product cordial labeling of EDG(comb) graph for m = 5

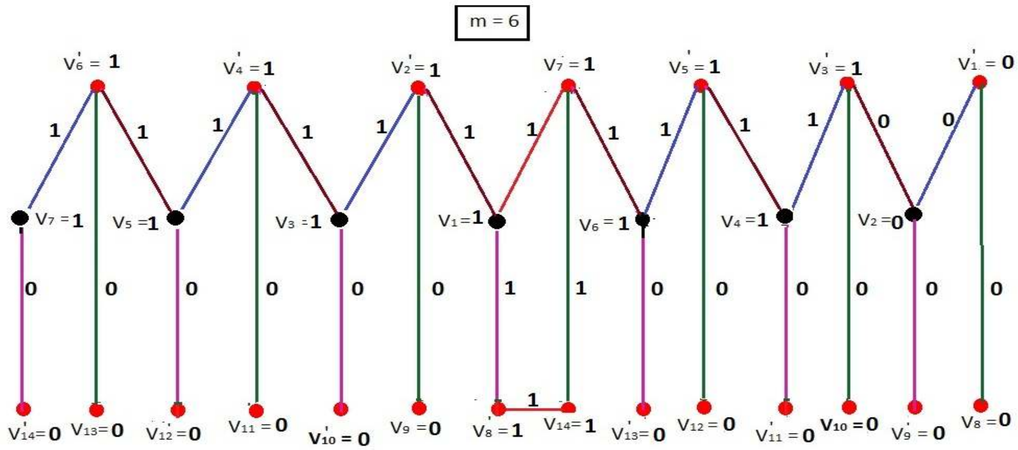

Fig. 4. Product cordial labeling of EDG(comb) graph for m = 6

Algorithm 2.3

Procedure: (Prime cordial labeling for extended duplicate graph of comb graph)
$V = \{v_1, v_2 \ldots\ldots v_{2m+2}, v_1', v_2' \ldots\ldots v_{2m+2}'\}$
// assignment of labels to vertices
$v_1 \leftarrow 4m-2$; $v_{m+2}' \leftarrow 4m+2$
for i = 2 to m-1 do
{ v_i = $2i$ if $i \equiv 0 \pmod 2$
$2m+2i-2$ otherwise
}
end for
for i = 1 to m-1 do
{v_i' = $2i$ if $i \equiv 1 \pmod 2$
$2m+2i-2$ otherwise
}
end for
for i = 2 to m do
{v_{m+i+1} = $2i-1$ if $i \equiv 1 \pmod 2$
$2m+2i-3$ otherwise
}
end for
for i = 2 to m do
{ v_{m+i+1}' = $2i-1$ if $i \equiv 0 \pmod 2$
$2m+2i-3$ otherwise
}
end for
if m = 2n
$v_m \leftarrow 2m$, $v_m' \leftarrow 1$, $v_{m+2} \leftarrow 4m+3$, $v_{m+1} \leftarrow 4m+1$
$v_{m+1}' \leftarrow 4m$, $v_{2m+2} \leftarrow 4m+4$, $v_{2m+2}' \leftarrow 4m-1$
if m = 2n+1
$v_m \leftarrow 4m+3$, $v_m' \leftarrow 2m$, $v_{m+1} \leftarrow 4m$ $v_{m+1}' \leftarrow 4m+1$, $v_{2m+2}' \leftarrow 4m+4$, $v_{2m+2} \leftarrow 4m-1$, $v_{m+2} \leftarrow 1$.
end procedure
output: vertex labeled extended duplicate graph of comb graph.

Theorem 2.5

The extended duplicate graph of comb graph, $m \geq 2$ admits prime Cordial labeling.

Proof:

The EDG (comb)(V,E) graph has 4 m+4 vertices and 4 m+4 edges. Label the vertices of EDG (comb) graph by defining a function $f : V \rightarrow \{1, 2, 3, 4, \ldots, 4m + 4\}$, as given in algorithm 2.3. Thus all the 4 m + 4 vertices are labeled.

Define the induced map $f^* : E \rightarrow N$ such that

$$f^*(v_i v_j) = \begin{cases} 1 & \text{if g.c.d.}\left(f(v_i), f(v_j)\right) = 1 \\ 0 & \text{if g.c.d.}\left(f(v_i), f(v_j)\right) > 1 \end{cases}$$

By the above induced function, the edge labels are obtained as follows :

For $1 \leq i \leq m-2$
$f^*(v_i v_{i+1}') = f^*(v_i' v_{i+1}) = 0$
For $1 \leq i \leq m$; $f^*(v_i' v_{m+i+1}) = 1$
For $2 \leq i \leq m$; $f^*(v_i v_{m+i+1}') = 1$
If m = 2n
$f^*(v_1 v_{m+1}') = f^*(v_1 v_{m+2}') = f^*(v_{m+1}' v_{2m+2}) = f^*(v_{m+2}' v_{2m+2}) = f^*(v_{m1}' v_m) = f^*(v_m v_{m+1}') = 0$
$f^*(v_{m-1} v_m') = f^*(v_m' v_{m+1}) = f^*(v_{m+1} v_{2m+2}') = 1$
If m = 2n + 1
$f^*(v_1 v_{m+1}) = f^*(v_1 v_{m+2}') = f^*(v_{m+1} v_{2m+2}') = f^*(v_{m+2}' v_{2m+2}') = f^*(v_{m-1} v_m') = f^*(v_m' v_{m+1}) = 0$
$f^*(v_{m-1}' v_m) = f^*(v_m v_{m+1}') = f^*(v_{m+1}' v_{2m+2}) = 1$

Thus in both the above cases,

The number of edges labeled with ‘1’ =m+m-1+3 =2 m+2.

Number of edges labeled with ‘0’ = m-2+m-2+6=2 m+2.

Hence the number of edges labeled with ‘1’ and ‘0’ differ by atmost ‘1’

Therefore EDG (comb) graph is prime cordial.

Example 2.3

Prime cordial labeling of EDG(comb) graphs for m=5 and m=6 are given in Figs. 5 and 6 respectively.

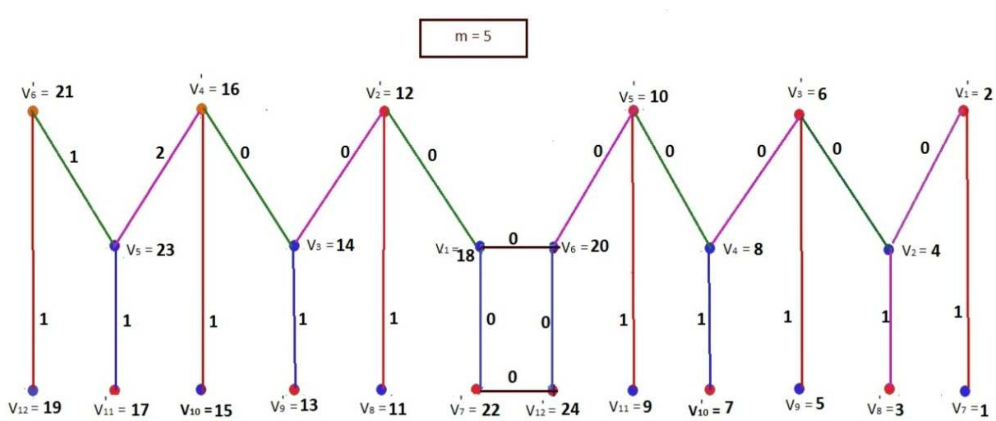

Fig. 5. Prime cordial labeling of EDG(comb) graph for m = 5

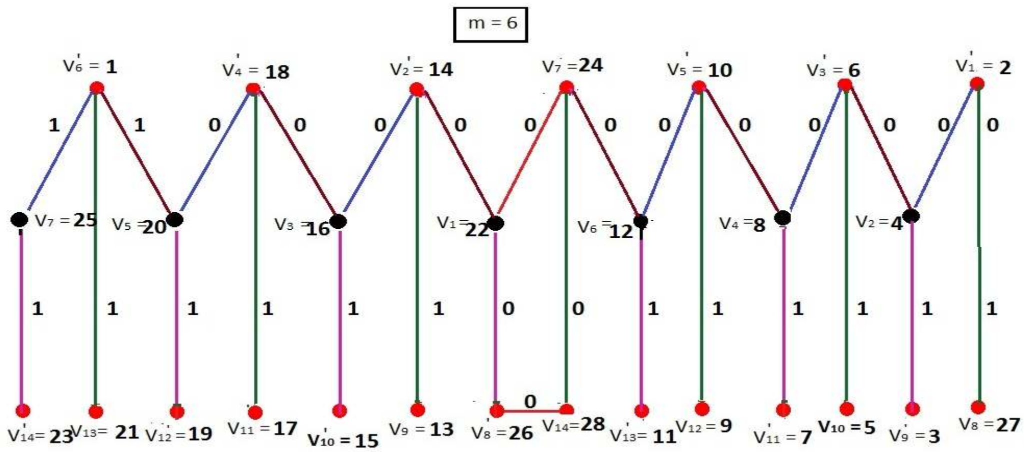

Fig. 6. Prime cordial labeling of EDG(comb) graph for m = 6

Algorithm 2.4

Procedure :(odd mean labeling for extended duplicate graph of comb graph)
V = {v_1 , v_2 . . . . . v_{2m+2} , v_1', v_2'. . . . . v_{2m+2}'}
// assignment of labels to vertices
for i = 1 to m+1 do
{ v_i = 2i-1 if i ≡ 0(mod 2)
2m+2i+1 otherwise

v_i' = 2i-1 if i ≡ 1(mod 2)
2m+2i+1 otherwise
}
end for
for i = 2 to m+2 do
{ v_{m+i} = 4m+2i+1 if i ≡ 0(mod 2)
6m+2i+3 otherwise
v_{m+i}' = 4m+2i+1 if i ≡ 1(mod 2)
6m+2i+3 otherwise
}
end for
end procedure
output: vertex labeled extended duplicate graph of comb graph.

Theorem 2.6

The extended duplicate graph of EDG (comb) graph admits odd mean labeling.

Proof:

Clearly EDG (comb)(V,E) graph has p = 4m+4 vertices and q = 4m+4 edges.

To label the vertices, define a function f: V → {1,3,5,……… 2q-1} as given in algorithm 2.4.

Thus all the 4m+4 vertices are labeled.

To get the edge labels, define the induced map

f* : E → {1,2,3…….,2q-1} such thatf*(v_iv_j) = f(v_i)+f(v_j)/2 for all v_iv_jє E

By the induced function, the edge labels are obtained as follows:
For 1 ≤ i ≤ m

$$f^*(v_iv_{i+1}') = \begin{cases} 2i & \text{if } i \equiv 0 \pmod 2 \\ 2m+2i+2 & \text{otherwise} \end{cases}$$

$$f^*(v_i'v_{i+1}) = \begin{cases} 2i & \text{if } i \equiv 1 \pmod 2 \\ 2m+2i+2 & \text{otherwise} \end{cases}$$

For $1 \le i \le m+1$

$$f^*(v_iv_{m+i+1}') = \begin{cases} 2m+2i+1 & \text{if } i \equiv 0 \pmod 2 \\ 4m+2i+3 & \text{otherwise} \end{cases}$$

$$f^*(v_i'v_{m+i+1}) = \begin{cases} 2m+2i+1 & \text{if } i \equiv 1 \pmod 2 \\ 4m+2i+3 & \text{otherwise} \end{cases}$$

If $m = 2n$

$f^*(v_1v_{m+1}') = 2m+2$, $f^*(v_{m+2}'v_{2m+2}) = 6m+6$.

If $m = 2n+1$

$f^*(v_1v_{m+1}) = 2m+2$, $f^*(v_{m+2}'v_{2m+2}') = 6m+6$.

Thus all the labeled edges are distinct.

Hence EDG (comb) graph admits odd mean labeling.

Example 2.4

Odd mean labeling of EDG (comb) graphs for m=5 and m=6 are given in Figs. 7 and 8 respectively.

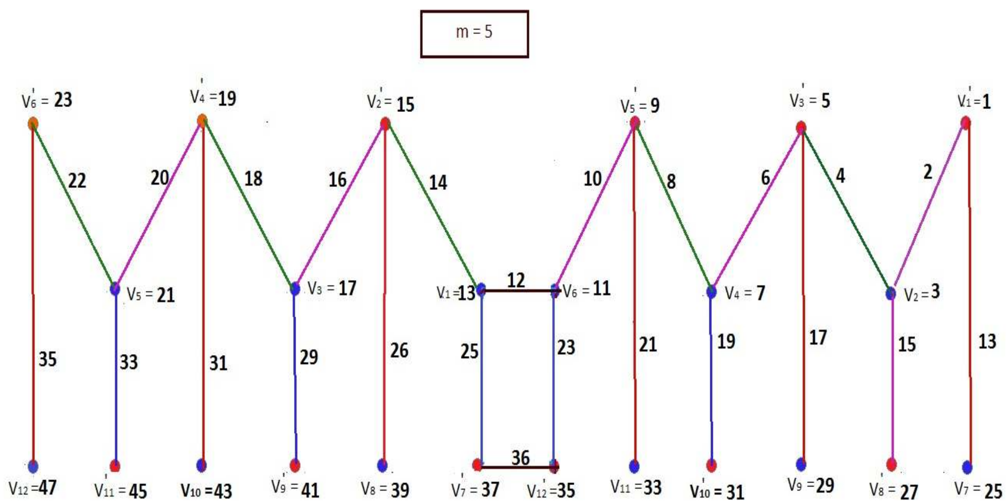

Fig. 7. Odd mean labeling of EDG(comb) graph for m = 5

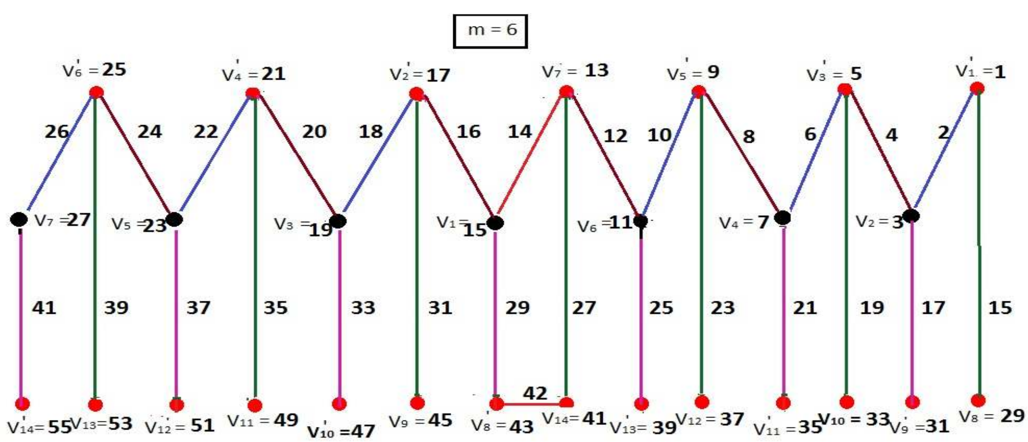

Fig. 8. Odd mean labeling of EDG(comb) graph for m = 6

Algorithm 2.5

Procedure: (Even mean labeling for extended duplicate graph of comb graph)
V = {v_1, v_2 . . . . . v_{2m+2}, v_1', v_2'. . . . . v_{2m+2}'}
// assignment of labels to vertices
for i = 1 to m+1 do
{ v_i = 2i if i ≡ 0(mod 2)
2m+2i+2 otherwise
v_i' = 2i if i ≡ 1(mod 2)
2m+2i+2 otherwise
}
end for
for i = 2 to m+2 do
{ v_{m+i} = 4m+2i+2 if i ≡ 0(mod 2)
6m+2i+4 otherwise
v_{m+i}' = 4m+2i+2 if i ≡ 1(mod 2)
6m+2i+4 otherwise
}
end for
end procedure
output: Vertex labeled extended duplicate graph of comb graph.

Theorem 2.7

The extended duplicate graph of comb graph, EDG (comb) graph admits even mean labeling.

Proof:

Clearly EDG (comb)(V,E) graph has p = 4m+4 vertices and q = 6m+4 edges.

To label the vertices, define a function

f : V → {2,4,6,………, 2q} as given in algorithm 2.5.

Thus 4 m+4 vertices are labeled.

To get the edge labels, define, the induced map f*: E → {1,2,3……..,2q} such that

$f^*(v_iv_j)$ = $[f(v_i)+f(v_j)]$ /2 for all v_iv_j ϵ E

By the induced function, the edge labels are obtained as follows:

For 1 ≤ i ≤ m
$f^*(v_iv_{i+1}')$ = 2i+1 if i ≡ 0 (mod 2)
2m+2i+3 otherwise
$f^*(v_i'v_{i+1})$ = 2i+1 if i ≡ 1 (mod 2)
2m+2i+3 otherwise
For 1 ≤ i ≤ m +1
$f^*(v_iv_{m+i+1}')$ = 2m+2i+2 if i ≡ 0 (mod 2)
4m+2i+4 otherwise
$f^*(v_i'v_{m+i+1})$ = 2m+ 2i+2 if i ≡ 1 (mod 2)
4m+2i+4 otherwise
If m = 2n
$f^*(v_1v_{m+1}')$ = 2m+3 ; $f^*(v_{m+2}'v_{2m+2})$ = 6m+7.
If m = 2n +1
$f^*(v_1v_{m+1})$ = 2m+3 ; $f^*(v_{m+2}'v_{2m+2}')$ = 6m+7.

Thus all the labeled edges are distinct.

Hence EDG (comb) graph admits even mean labeling.

Example 2.5

Even mean labeling of EDG (comb) graph for m = 5 and m = 6 are given in Figs. 9 and 10 respectively.

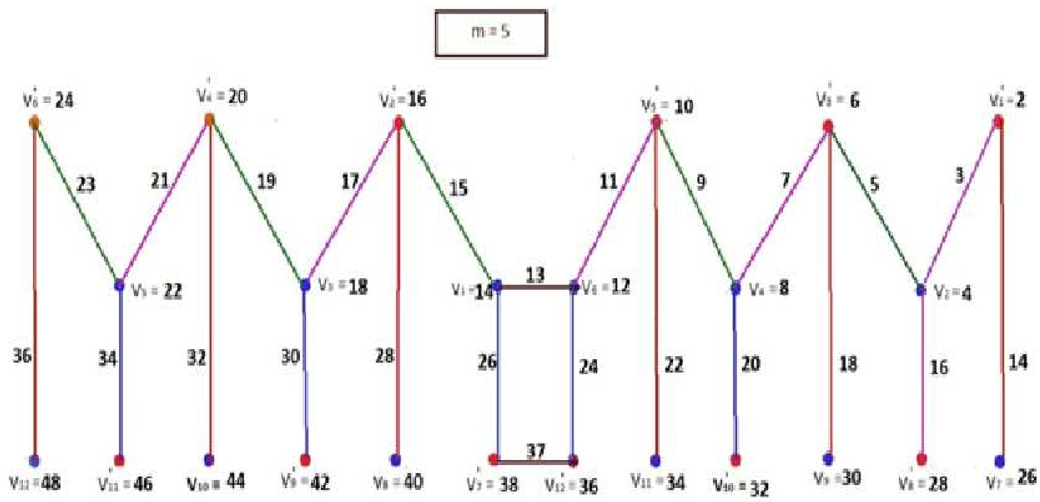

Fig. 9. Even mean labeling of EDG(comb) graph for m = 5

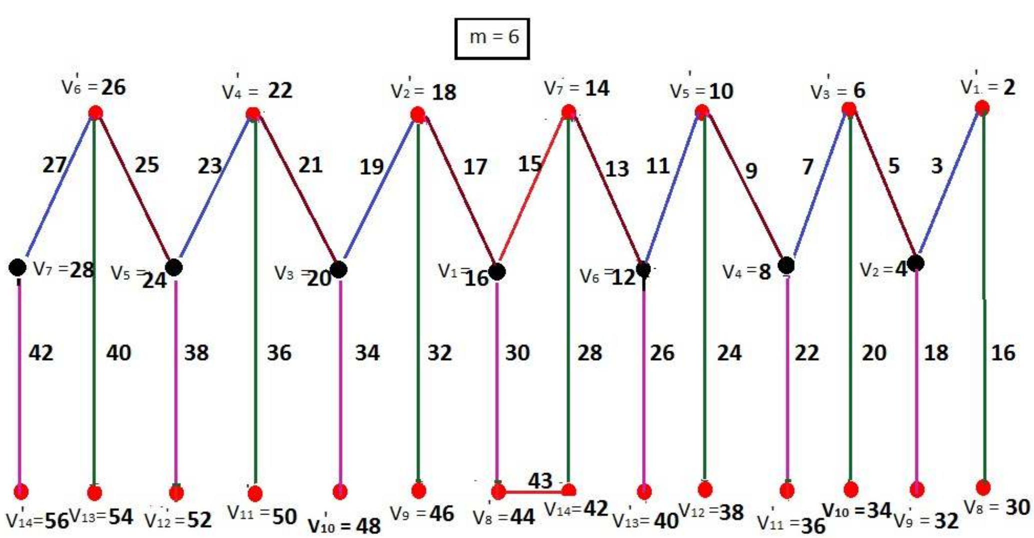

Fig. 10. Even mean labeling of EDG(comb) graph for m = 6

3. CONCLUSION

In this paper we have presented algorithms and proved that the extended duplicate graph of Comb graph admits cordial, total cordial, product cordial, total product cordial,prime cordial, odd mean labeling and even mean labeling.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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