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Star-in-Coloring of Some New Class of Graphs

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Abstract: *Jan Mycielski defined the Mycielskian graph as an extension of a graph with certain conditions. Sampathkumar and Walikar by omitting some of the conditions of Mycielski graph obtained the splitting graph of a graph. In this paper, we found the star-in-coloring concept introduced by Sudha, et al for the following graphs:*

(i) the splitting graph of complete-bipartite graphs

(ii) theMycielski's graphs of paths

(iii) theMycielski's graphs of cycles

(iv) tensor product of complete-bipartite graphs and paths

(v) tensor product of complete-bipartite graphs and cycles.

In addition we have given the general coloring pattern of all these graphs and their star-in-chromatic number.

Keywords: *star-in-coloring, splitting graph, Mycielski graph, tensor product of two graphs*

AMS Subject Classification: 05C15

1. Introduction

In 1973, Grunbaum[1] has defined proper coloring by avoiding 2-colored paths with four vertices and defined it as star-in-coloring. Star-in-coloring has been discussed by Fertin, et al[2] and Nesetril, et al[3]. Jan Mycielski[4] in 1955 has given the construction of Mycielski graph for the graphs. Splitting graph S(G) was defined by Sampathkumar and Walikar[5]. The tensor product of graphs was defined by Alfred North Whitehead, et al[6] in their Principia Mathematica.

Definition 1.1 A star-coloring of a graph G is a proper coloring of a graph with the condition that no path on four vertices (P_4) is 2-colored.

A k $-$star-coloring of a graph G is a star-coloring of G using atmost k colors.

Definition1.2 An in-coloring of a graph G is a proper coloring of a graph G if there exist any path $P_3$of length 2 with the end vertices having same color, then the edges of P_3 are oriented towards the central vertex.

By combining these two definitions, Sudha, et al[7,8] defined the star-in-coloring of graphs as follows:

Definition1.3 A graph G is said to admit star-in-coloring orientation if

1. No path on four vertices is bicolored

2. Any path of length 2 with end vertices of same color are directed towards the middle vertex.

The minimum number of colors required to color the graph G satisfying the above conditions for star-in-coloring is called the star-in-chromatic number of G and is denoted by $\chi_{si}(G)$.

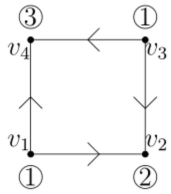


Figure 1. Cycle C_4

In fig-1, the vertices v_1 and v_3 are assigned with the color 1, the vertex v_2 is assigned with the color 2 and the vertex v_4 is assigned with the color 3. This pattern of coloring satisfies both the conditions required for star-in-coloring orientation. In this graph we see that no two adjacent vertices have the same color; no path on four vertices is bicolored; each and every edge in a path of length two in which end vertices have same color are oriented towards the central vertex. Hence it is star-in-colored with orientation.

Definition1.4 For any graph$G$, the splitting graph $S(G)$ is obtained by adding to each vertex v_i in G a new vertex v_i' such that v_i' is adjacent to the neighbors of v_i in G.

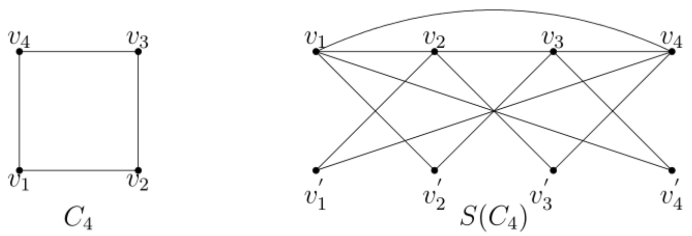


Figure 2. Cycle C_4 and its splitting graph $S(C_4)$

Definition1.5 Let G be a graph with n vertices denoted by $v_1, v_2, \cdots, v_n$. The Mycielski graph $\mu(G)$ is obtained by adding to each vertex v_i a new vertex u_i such that u_i is adjacent to the neighbors of v_i. Finally, add a new vertex w such that w is adjacent to each and everyu_i.

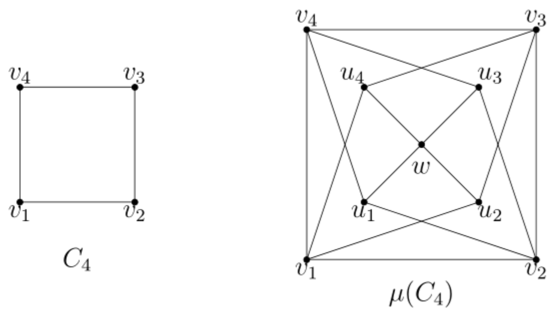


Figure 3. Cycle C_4 and its Mycielski's graph $\mu(C_4)$

Definition1.6 The tensor product of two graphs G_1 and G_2 denoted by $G_1 \otimes G_2$ has the vertex set $V(G_1 \otimes G_2) = V(G_1) \times V(G_2)$ and the edge set $E(G_1 \otimes G_2) = \{(u_1, v_1)(u_2, v_2)/u_1u_2 \in E(G_1)$ and$v_1v_2 \in E(G_2)\}$.

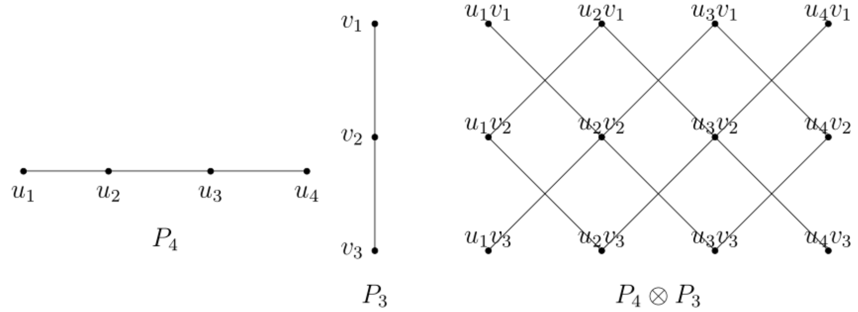


Figure 4. Tensor product of P_4 and P_3

2. MAIN RESULTS

Theorem 2.1 The splitting graph of complete-bipartite graphs $S(K_{m,n})$ admit star-in- coloring and its star-in-chromatic number is $\chi_{si}(S(K_{m,n})) = 2(min(m,n)) + 1$ for all m and n.

Proof. The complete-bipartite graph $K_{m,n}$ consists of $m+n$ vertices $\{u_1, u_2, \cdots, u_{m+n}\}$ and mn edges. The splitting graph of complete-bipartite graph $K_{m,n}$ consists of $2(m+n)$vertices and$3mn$ edges. It is denoted by $S(K_{m,n})$.

Define a function $f : V \to \{1,2,3,\ldots\}$ such that $f(u) \neq f(v)$ if $uv \in E$ where V is the vertex set of $S(K_{m,n})$ and E is the edge set of $S(K_{m,n})$.

The coloring pattern is as follows:

Case (i): If$m \leq n$

$$f(u_i) = \begin{cases} 1+i, & 1 \leq i \leq m \\ 1, & m+1 \leq i \leq m+n \end{cases}$$

$$f(u_i^{'}) = \begin{cases} m+1+i, & 1 \leq i \leq m \\ 1, & m+1 \leq i \leq m+n \end{cases}$$

Case (ii): If $m > n$

$$f(u_i) = \begin{cases} 1, & 1 \leq i \leq m \\ 1-m+i, & m+1 \leq i \leq m+n \end{cases}$$

$$f(u_i^{'}) = \begin{cases} 1, & 1 \leq i \leq m \\ 1-m+n+i, & m+1 \leq i \leq m+n \end{cases}$$

With this pattern we can color the graph $S(K_{m,n})$ satisfying star-in-coloring condition.

Illustration 2.1.1 Consider a complete-bipartite graph $K_{2,4}$. As per the definition of splitting graph$S(K_{2,4})$ consists of 12 vertices and 24 edges.

According to case(i) of theorem-2.1 the vertices u_1 and u_2 are assigned with colors 2 and 3 respectively. The vertices u_3, u_4, u_5 and u_6 take the color 1. The vertices $u_1^{'}$ and $u_2^{'}$ are assigned with colors 4 and 5 respectively. The vertices $u_3^{'}, u_4^{'}, u_5^{'}$ and $u_6^{'}$ take the color 1.

The star-in-chromatic number of $S(K_{2,4})$ is 5.

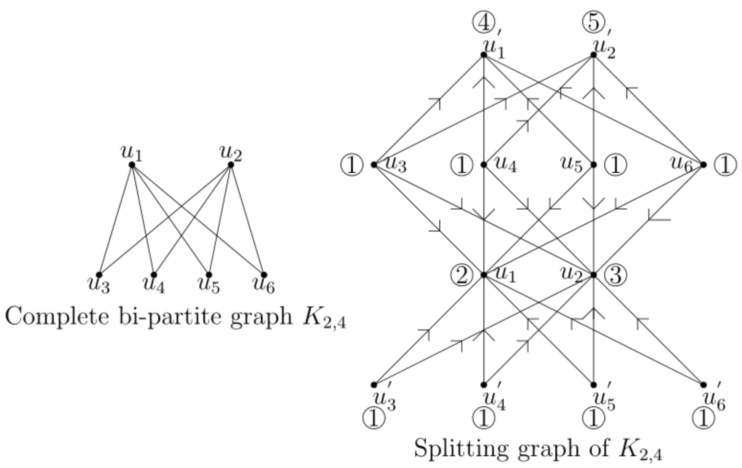


Figure 5. Star-in-coloring of $S(K_{2,4})$

Theorem 2.2 Mycielski's graph of path $\mu(P_n)$ for all odd $n \geq 2$ admit star-in-coloring and its star-in-chromatic number is $\chi_{si}(\mu(P_n)) = 5 + j$with $j = \left(\frac{n-3}{2}\right)$.

Proof. Consider a path P_n with n vertices and $n-1$ edges. Let the vertices be denoted by $v_1, v_2, \cdots, v_n$. As per the construction of Mycielski's graph a new vertex set say $\{u_1, u_2, \cdots, u_n\}$ is introduced and each and every vertex say u_i is adjacent to the neighbor of v_i for all i. Then another new vertex say w is introduced and an edgeisadded from$w$to each u_i for all i. This newly constructed graph$\mu(P_n)$ consists of $(2n + 1)$ vertices and $4n - 3$ edges.

Define a function $f : V \rightarrow \{1,2,3,\dots\}$ such that $f(u) \neq f(v)$ if $uv \in E$ where V is the vertex set of $\mu(P_n)$ and E is the edge set of $\mu(P_n)$ as follows:

$$f(v_i) = \begin{cases} 1, & if i \equiv 1 (mod\ 4) and i \equiv 3 (mod\ 4) \\ 2, & if i \equiv 2 (mod\ 4) \\ 3, & if i \equiv 0 (mod\ 4) \end{cases}$$

$$f(u_i) = \begin{cases} 4, & if i \equiv 1 (mod\ 4) and i \equiv 3 (mod\ 4) \\ 4 + \left(\frac{i}{2}\right), & if i \equiv 2 (mod\ 4) and i \equiv 0 (mod\ 4) \end{cases}$$

$$f(w) = 1$$

By using the above pattern of coloring the Mycielski graph of paths is star-in- colored.

Illustration 2.2.1 Consider the path graphP_{11}. According to the construction of Mycielski graph we obtain the graph $\mu(P_{11})$. It consists of 23 vertices and 41 edges.

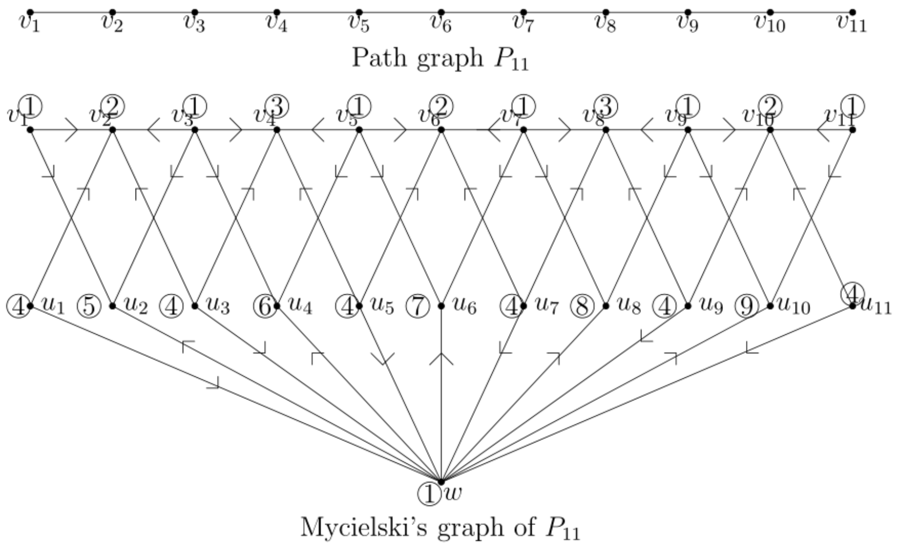


Figure 7. Star-in-coloring of Mycielski's graph $\mu(P_{11})$

By using theorem-2.2 the vertices v_1, v_3, v_5, v_7, v_9 and v_{11} take the color 1. The vertices v_2, v_6 and v_{10} take the color 2. The vertices v_4 and v_8 take the color 3. The vertices $u_1, u_3, u_5, u_7, u_9$and u_{11} take the color 4. The vertices u_2, u_4, u_6, u_8 and u_{10} are assigned with colors 5,6,7,8 and 9 respectively.The vertex w takes the color 1.

The star-in-chromatic number of $\mu(P_{11})$is 9.

Remark: For $n$even$\mu(P_n)$ there isatleast one edge without orientation. Hence Star-in-coloring condition is not satisfied.

Theorem 2.3 Mycielski graph of cycles $\mu(C_n)$ for all even $n \geq 3$ admit star-in-coloring and its star-in-chromatic number is

$$\chi_{si}\big(\mu(C_n)\big) = \begin{cases} 2(2+j), & if n = 4j, j = 1,2,3, \dots \\ 2(3+j), & if n = 2 + 4j, j = 1,2,3, \dots \end{cases}$$

Proof: Consider a cycle C_n with n vertices and n edges. The vertices are denoted by $v_1, v_2, \cdots, v_n$.As per the construction of Mycielski's graph a new vertex set$\{u_1, u_2, \cdots, u_n\}$ is introduced and draw an edge from each vertex u_i to the neighbor of v_i for all i. A new vertex w is introduced and we add an edge from w to each u_i. This newly constructed graph $\mu(C_n)$ consists of $(2n + 1)$ vertices and $4n$ edges.

Define a function $f : V \rightarrow \{1,2,3,\dots\}$ such that $f(u) \neq f(v)$ if $uv \in E$ where V is the vertex set of μ(Cn) and E is the edge set of $\mu(C_n)$as follows:

Case (i): If $n = 4j,\ j = 1,2,3,\ldots$

$$f(v_i) = \begin{cases} 1, & if i \equiv 1(mod\ 4) and i \equiv 3(mod\ 4) \\ 2, & if i \equiv 2(mod\ 4) \\ 3, & if i \equiv 0(mod\ 4) \end{cases}$$

$$f(u_i) = \begin{cases} 4, & if i \equiv 1(mod\ 4) and i \equiv 3(mod\ 4) \\ 4 + \left(\frac{i}{2}\right), & if i \equiv 2(mod\ 4) and i \equiv 0(mod\ 4) \end{cases}$$

$$f(w) = 1$$

Case (ii): If $n = 2 + 4j,\ j = 1,2,3,\ldots$

$$f(v_i) = \begin{cases} 1, & if i \equiv 1(mod\ 4) and i \equiv 3(mod\ 4) \\ 2, & if i \equiv 2(mod\ 4) and i < n \\ 3, & if i \equiv 0(mod\ 4) \end{cases}$$

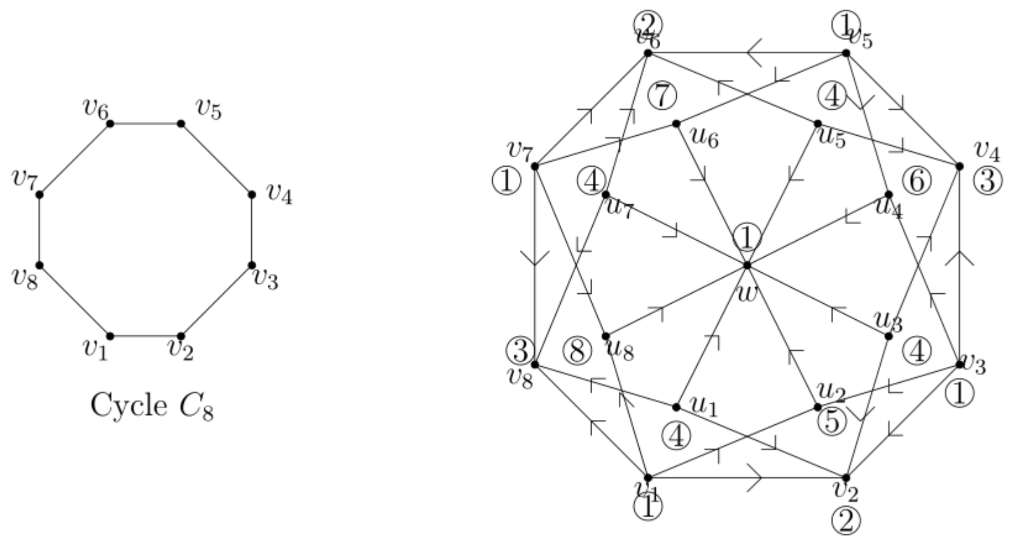
$$f(v_n) = 4$$

$$f(u_i) = \begin{cases} 5, & if i \equiv 1(mod\ 4) and i \equiv 3(mod\ 4) \\ 5 + \left(\frac{i}{2}\right), & if i \equiv 2(mod\ 4) and i \equiv 0(mod\ 4) \end{cases}$$

$$f(w) = 1$$

By using the above pattern of coloring the Mycielski's graph of cycles C_n for all even $n \geq 3$ is star-in-colored.

Illustration 2.3.1 Consider thecycle C_8. According to the construction of Mycielski graph $\mu(C_8)$ consists of 17 vertices and 32 edges.



Cycle C_8 Mycielski's graph of C_8

Figure 8. Star-in-coloring of $\mu(C_8)$

By using case(i) of theorem-2.3, the vertices v_1, v_3, v_5, v_7 and w take the color 1. The vertices v_2 and v_6 take the color 2. The vertices v_4 and v_8 take the color 3. The vertices u_1, u_3, u_5 and u_7 take the color 4. The vertices u_2, u_4, u_6 and u_8 are assigned with colors 5,6,7 and 8 respectively.

The star-in-chromatic number of $\mu(C_8)$ is 8.

Theorem2.4 The tensor product of complete-bipartite graph and a path admits star-in-coloring and its star-in-chromatic number is

$$\chi_{si}(K_{m,n} \otimes P_r) = \begin{cases} \min(m,n)+1, & if r = 2 \\ 2(\min(m,n))+1, & if r > 2 \end{cases}$$

Proof. Consider a complete-bipartite graph $K_{m,n}$ which consists of $m+n$ vertices denoted by $u_1, u_2, \cdots, u_{m+n}$ and mn edges and the path graph P_r which consists of r vertices denoted by $v_1, v_2, \cdots, v_r$ and $r-1$ edges. The tensor product of $K_{m,n}$ and P_r is obtained as per the definition-6. This newly obtained graph consists of $r(m+n)$ vertices and $2mn(r-1)$ edges.

Define a function $f : V \to \{1,2,3,\dots\}$ such that $f(u) \neq f(v)$ if $uv \in E$ where V is the vertex set of $K_{m,n} \otimes P_r$ and E is the edge set of $K_{m,n} \otimes P_r$ as follows:

Case (i): If $m \leq n$

For $j \equiv 1(mod\ 4)$ and $j \equiv 2(mod\ 4)$

$$f(u_i v_j) = \begin{cases} i+1, & for\ 1 \leq i \leq m and\ 1 \leq j \leq r \\ 1, & for m+1 \leq i \leq m+n and\ 1 \leq j \leq r \end{cases}$$

For $j \equiv 3(mod\ 4)$ and $j \equiv 0(mod\ 4)$

$$f(u_i v_j) = \begin{cases} m+i+1, & for\ 1 \leq i \leq m and\ 1 \leq j \leq r \\ 1, & for m+1 \leq i \leq m+n and\ 1 \leq j \leq r \end{cases}$$

Case (ii): If $m > n$

For $j \equiv 1(mod\ 4)$ and $j \equiv 2(mod\ 4)$

$$f(u_i v_j) = \begin{cases} 1, & for\ 1 \leq i \leq m and\ 1 \leq j \leq r \\ 1-m+i, & for m+1 \leq i \leq m+n and\ 1 \leq j \leq r \end{cases}$$

For $j \equiv 3(mod\ 4)$ and $j \equiv 0(mod\ 4)$

$$f(u_i v_j) = \begin{cases} 1, & for\ 1 \leq i \leq m and\ 1 \leq j \leq r \\ n-m+1+i, & for m+1 \leq i \leq m+n and\ 1 \leq j \leq r \end{cases}$$

By using this pattern of coloring the graph is be star-in-colored.

Illustration2.4.1 Consider a complete-bipartite graph $K_{2,3}$ and a path P_3. The tensor product of $K_{2,3}$ and P_3 consists of 15 vertices and 24 edges.

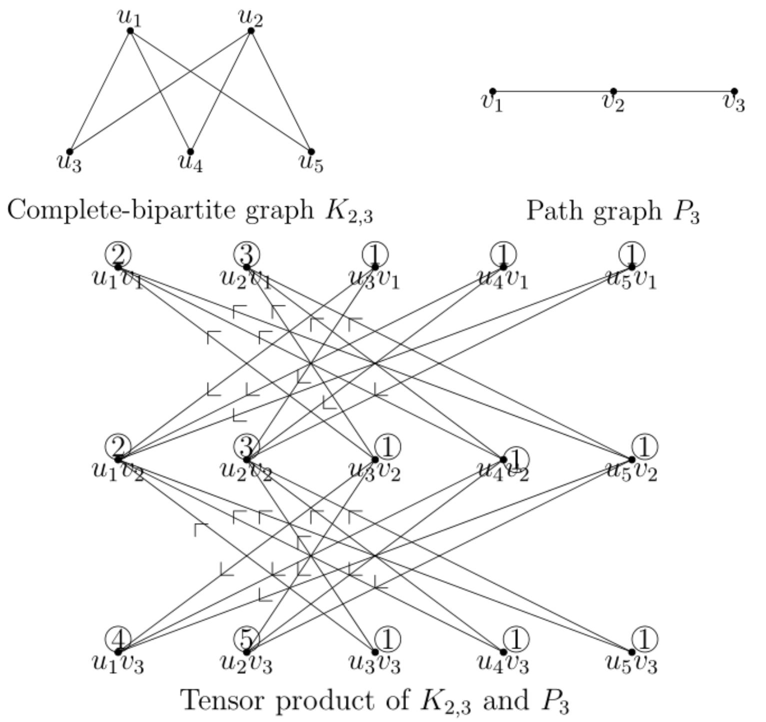


Figure 10. Star-in-coloring of $K_{2,3} \otimes P_3$

By using case(i) of theorem-2.4 the vertices in $K_{2,3} \otimes P_3$ are assigned with colors 1,2,3,4 and 5 which satisfy the conditions of star-in-coloring.

Thus the star-in-chromatic number of $K_{2,3} \otimes P_3$is 5.

Remark: The case $m > n$ is the mirror image of case $m \leq n$.

Theorem 2.5 The tensor product of complete-bipartite graph and a cycle admits star-in-coloring and its star-in-chromatic number is given by

$$\chi_{si}(K_{m,n} \otimes C_s) = \begin{cases} 3(\min(m,n)) + 1, & if s \equiv 1(mod\ 4),\ s \equiv 2(mod\ 4),\ s \equiv 3(mod\ 4) \\ 2(\min(m,n)) + 1, & if s \equiv 0(mod\ 4) \end{cases}$$

Proof. Consider a complete-bipartite graph $K_{m,n}$ which consists of $m + n$ vertices denoted by $u_1, u_2, \cdots, u_{m+n}$and mn edges and a cycle graph C_s which consists of s vertices denoted by $v_1, v_2, \cdots, v_s$ and s edges. The tensor product of $K_{m,n}$ and C_s is obtained as per the definition-6. This newly obtained graph consists of $s(m + n)$ vertices and $2mns$ edges.

Define a function $f : V \to \{1,2,3,\dots\}$ such that $f(u) \neq f(v)$ if $uv \in E$ where V is the vertex set of $K_{m,n} \otimes C_s$ and E is the edge set of $K_{m,n} \otimes C_s$as follows:

There are two cases one for $m \leq n$ and other for $m > n$.

Case (i): For $m \leq n$

If $s \equiv 1(mod\ 4)$

$$f(u_i v_j) = \begin{cases} 1 + i, & if\ 1 \leq i \leq m\ with\ j \equiv 0(mod\ 4) and\ j \equiv 1(mod\ 4),\ j \neq s - 1 \\ m + 1 + i, & if\ 1 \leq i \leq m\ with\ j \equiv 2(mod\ 4) and\ j \equiv 3(mod\ 4) \\ 2m + 1 + i, & if\ 1 \leq i \leq m\ and\ j = s - 1 \\ 1, & if\ m + 1 \leq i \leq m + n\ and\ for\ all\ j \end{cases}$$

If$s \equiv 2(mod\ 4)$

$$f(u_i v_j) = \begin{cases} 1 + i, & if\ 1 \leq i \leq m\ with\ j \equiv 1(mod\ 4) and\ j \equiv 2(mod\ 4),\ j < s - 1 \\ m + 1 + i, & if\ 1 \leq i \leq m\ with\ j \equiv 3(mod\ 4) and\ j \equiv 0(mod\ 4) \\ 2m + 1 + i, & if\ 1 \leq i \leq m\ and\ j = s\ and\ j = s - 1 \\ 1, & if\ m + 1 \leq i \leq m + n\ and\ for\ all\ j \end{cases}$$

If$s \equiv 3(mod\ 4)$

$$f(u_i v_j) = \begin{cases} 1 + i, & if\ 1 \leq i \leq m\ with\ j \equiv 1(mod\ 4) and\ j \equiv 2(mod\ 4),\ j \neq s - 1 \\ m + 1 + i, & if\ 1 \leq i \leq m\ with\ j \equiv 3(mod\ 4) and\ j \equiv 0(mod\ 4) \\ 2m + 1 + i, & if\ 1 \leq i \leq m\ and\ j = s - 1 \\ 1, & if\ m + 1 \leq i \leq m + n\ and\ for\ all\ j \end{cases}$$

If$s \equiv 0(mod\ 4)$

$$f(u_i v_j) = \begin{cases} 1 + i, & if\ 1 \leq i \leq m\ with\ j \equiv 1(mod\ 4) and\ j \equiv 2(mod\ 4) \\ m + 1 + i, & if\ 1 \leq i \leq m\ with\ j \equiv 3(mod\ 4) and\ j \equiv 0(mod\ 4) \\ 1, & if\ m + 1 \leq i \leq m + n\ and\ for\ all\ j \end{cases}$$

Case (ii): For $m > n$

If$s \equiv 1(mod\ 4)$

$$f(u_i v_j) = \begin{cases} 1, & if\ 1 \leq i \leq m\ and\ for\ all\ j \\ 1 - m + i, & if\ m + 1 \leq i \leq m + n\ with\ j \equiv 1(mod\ 4) and\ j \equiv 0(mod\ 4),\ j \neq s - 1 \\ n - m + 1 + i, & if\ m + 1 \leq i \leq m + n\ with\ j \equiv 2(mod\ 4) and\ j \equiv 3(mod\ 4) \\ 2n - m + 1 + i, & if\ m + 1 \leq i \leq m + n\ and\ j = s - 1 \end{cases}$$

If$s \equiv 2(mod\ 4)$

$$f(u_i v_j) = \begin{cases} 1, & if\ 1 \leq i \leq m\ and\ for\ all\ j \\ 1 - m + i, & if\ m + 1 \leq i \leq m + n\ with\ j \equiv 1(mod\ 4) and\ j \equiv 2(mod\ 4),\ j < s - 1 \\ n - m + 1 + i, & if\ m + 1 \leq i \leq m + n\ with\ j \equiv 3(mod\ 4) and\ j \equiv 0(mod\ 4) \\ 2n - m + 1 + i, & if\ m + 1 \leq i \leq m + n\ and\ j = s\ and\ j = s - 1 \end{cases}$$

If $s \equiv 3(mod\ 4)$

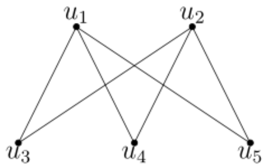
$$f(u_i v_j) = \begin{cases} 1, & if\ 1 \le i \le m\ and\ for\ all\ j \\ 1 - m + i, & if\ m+1 \le i \le m+n\ with\ j \equiv 1(mod\ 4) and\ j \equiv 2(mod\ 4),\ \ j \ne s-1 \\ n - m + 1 + i, & if\ m+1 \le i \le m+n\ with\ j \equiv 3(mod\ 4) and\ j \equiv 0(mod\ 4) \\ 2n - m + 1 + i, & if\ m+1 \le i \le m+n\ and\ j = s-1 \end{cases}$$

If $s \equiv 0(mod\ 4)$

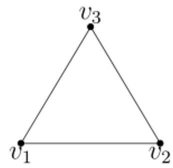
$$f(u_i v_j) = \begin{cases} 1, & if\ 1 \le i \le m\ and\ for\ all\ j \\ 1 - m + i, & if\ m+1 \le i \le m+n\ with\ j \equiv 1(mod\ 4) and\ j \equiv 2(mod\ 4) \\ n - m + 1 + i, & if\ m+1 \le i \le m+n\ with\ j \equiv 3(mod\ 4) and\ j \equiv 0(mod\ 4) \end{cases}$$

With this pattern of coloring, the tensor product of $K_{m,n}$ and C_s can be star-in-colored.

Illustration 2.5.1 Consider a complete-bipartite graph $K_{2,3}$ and a cycle C_3. The tensor product of $K_{2,3}$ and C_3 consists of 15 vertices and 36 edges.



Complete-bipartite graph $K_{2,3}$



Cycle C_3

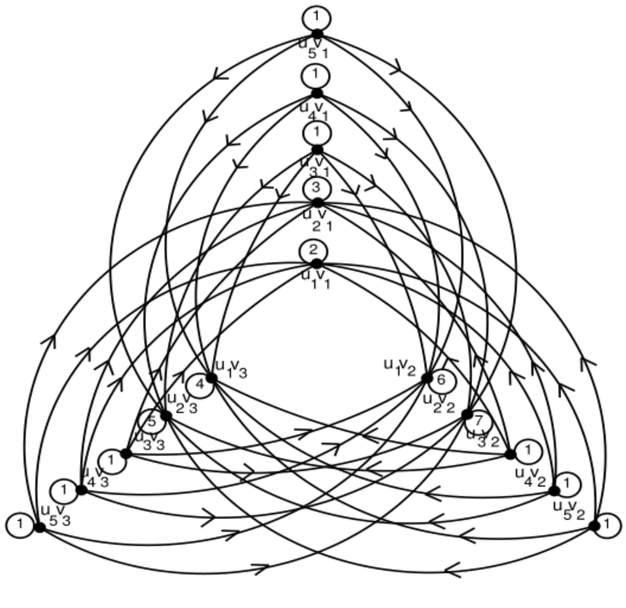


Figure 12. Star-in-coloring of $K_{2,3} \otimes C_5$

By using case(i) of theorem-2.5 the vertices in $K_{2,3} \otimes C_3$ are assigned with colors 1,2,3,4,5,6 and 7which satisfy the conditions of star-in-coloring.

The star-in-chromatic number of $K_{2,3} \otimes C_3$ is 7.

3. Conclusion

In this paper, we have proved that the following graphs are star-in-colored with orientation by giving the general pattern of coloring and their star-in-chromatic number is also found:

(i) the star-in-chromatic number of $S(K_{m,n})$ is $2(min(m,n)) + 1$

(ii) the star-in-chromatic number of $\mu(P_n)$ is $\frac{1}{2}(n+7)$

(iii) the star-in-chromatic number of $\mu(C_n)$ is $2(2+j)$ if $n = 4j$ and $2(3+j)$ if $n = 2+4j$ where $j = 1,2,3, \ldots$

(iv) the star-in-chromatic number of $K_{m,n} \otimes P_r$ is $min(m,n) + 1$ if $r = 2$ and $2(min(m,n)) + 1$if $r > 2$

(v) the star-in-chromatic number of $K_{m,n} \otimes C_s$ is $2(min(m,n)) + 1$ if $s \equiv 0(mod\ 4)$ and $3(min(m,n)) + 1$ if $s \equiv 1(mod\ 4)$ or $s \equiv 2(mod\ 4)$ or $s \equiv 3(mod\ 4)$.

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