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Distance based indices of Bipartite graphs associated with 3-uniform Semigraph of Cycle graph

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Abstract

In this paper, some topological indices namely, Wiener index, Detour index, Circular index, vertex PI index and Co PI index of the bipartite graphs associated with the 3-uniform semi graph $C_{m,1}$ are derived.

Keywords: Semi graph, Wiener index, Detour index, Circular index, vertex PI index and Co-PIindex.

1. INTRODUCTION

Let $G=\left(V\left(G\right),E\left(G\right)\right)$ be a simple, connected and undirected graph, where $V\left(G\right)$ is the vertex set of Gand $E\left(G\right)$ is the edge set of G. For any two vertices $u,v\in V\left(G\right)$, the shortest distance between $u\ and\ v$ is denoted by $d\left(u,v\right)$, the longest distance between $u\ and\ v$ is denoted by $D\left(u,v\right)$, the sum of the longest distance and shortest distance between u *and* v, called as circular distance is denoted by $d^0(u,v)$.

The Wiener index[4] of G is defined as $W(G)=\frac{1}{2}\sum_{u,v\in V(G)} d(u,v)$ with the summation taken over all pairs of distinct vertices of G. In the same manner the Detour index[3] of G is defined as $D(G)=\frac{1}{2}\sum_{u,v\in V(G)} D(u,v)$, the Circular index of G is defined as $C(G)=\frac{1}{2}\sum_{u,v\in V(G)} \left(D(u,v)+d(u,v)\right)$ and the Cut Circular index of G is defined as $CC(G)=\frac{1}{2}\sum_{u,v\in V(G)} \left(D(u,v)-d(u,v)\right)$. For an edge $e=uv\in E(G)$, the number of vertices of G whose distance to the vertex u is smaller than the distance to the vertex v in G is denoted by $n_u^G(e)$ and the number of vertices of G whose distance to the vertex v is smaller than the distance to the vertex u in G is denoted by $n_v^G(e)$, the vertices with equidistance from the ends of the edge $e=uv$ are not counted. The vertex PI index of G, denoted by PI(G), is defined as $PI(G)=\sum_{e=uv\in E(G)} \left[n_u^G(e)+n_v^G(e)\right]$. If G is a bipartite graph, then $PI(G)=\left|V(G)\right|\cdot\left|E(G)\right|$[1]. The Co - PI index of G, denoted by Co - PI(G) is defined as $Co-PI(G)=\sum_{e=uv\in E(G)} \left|n_u^G(e)-n_v^G(e)\right|$.

2. SEMIGRAPH AND BIPARTITE GRAPHS ASSOCIATED WITH SEMI GRAPH

2.1 Semigraph

Semigraph is a natural generalization of graph in which an edge may have more than two vertices by containing middle vertices apart from the usual end vertices. Semigraphs, introduced by E.Sampathkumar[6], is an interesting type of generalization of the concept of graph. S.S.Kamath and R.S.Bhat[2] introduced adjacency domination in semigraphs. Also S.S.Kamath and Saroja.R.Hbber[5] introduced strong and weak domination in semigraphs. Semi graphs have elegant pictorial representation and several results have been extended from graph theory to semigraphs. Y.B.Venkatakrishnan and V.Swaminathan[7] introduced bipartite theory of semigraphs. Given a semigraph they constructed bipartite graphs which represents the arbitrary graphs.

A semigraph S is a pair (V,X), where V is a non empty set whose elements are called vertices of S and X is a set of $n-tuples$ of distinct vertices called edges of S for various $n \geq 2$ satisfying the following conditions :

(a) any two edges have at most one vertex in common.

(b) two edges $(u_1,u_2,...,u_m)$ and $(v_1,v_2,...,v_n)$ are considered to be equal if and only if (i) $m=n$ and (ii) either $u_i = v_i \ for\ 1 \leq i \leq n\ or\ u_i = v_{n-i+1}\ for\ 1 \leq i \leq n.$

Thus, the edges $(u_1,u_2,...,u_m)$ is same as $(u_m,u_{m-1},...,u_1)$.

If $e=(v_1,v_2,...,v_n)$ is an edge of a semigraph, we say that $v_1\ and\ v_n$ are the end vertices of the edge e and $v_i,\ 2 \leq i \leq n-1$, are the middle vertices or m – vertices of the edge e and also the vertices $v_1,v_2,...,v_n$, are said to belong to the edge e. A semigraph with p vertices and q edges is called a (p,q)- semigraph. Two vertices $u\ and\ v,\ u \neq v$, in a semigraph are adjacent if both off them belong to the same edge. The number of vertices in an edge e is called cardinality of e and it is denoted by $|e|$. A semigraph S is said to be r- uniform if the cardinality of each edge in S is r. By introducing n number of middle vertices to each edge of the graph C_m, where C_m is the cycle with m vertices, we get a semigraph with $(n+2)$ uniform which is denoted as $C_{m,n}$.

Example 1.1 Let $S=(V,X)$ be a semigraph, where $V=\{1,2,...,10\}\ and$ $X=\{(1,2),(3,6,8),(6,9,10),(2,10),(3,4,5),(1,5)\}$. The graph S is given in the Figure 1

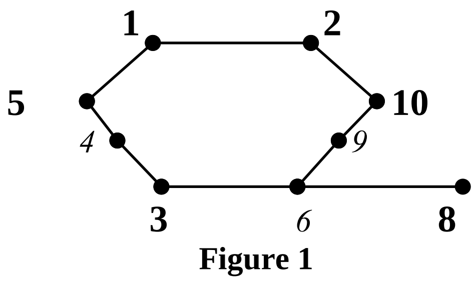

Figure 1

2.2 Bipartite graphs associated with semigraph

Let V' be the another copy of the vertex set V of a semigraph S. Then the following graphs represents the bipartite graph associated with the semigraph S.

Bipartite graph A(S) :

The bipartite graph $A(S)=(V,V',X)$, where $X=\{(u,v')/\,u\ and\ v\ belong\ to\ the\ same\ edge\ of\ the\ semigraph\ S\}$.

Bipartite graph A⁺(S) :

The bipartite graph $A^{+}(S)=(V,V',X)$, where $X=\{(u,v')/\,u\ and\ v\ belong\ to\ the\ same\ edge\ of\ the\ semigraph\ S\}\cup\{(u,u')/\,u\in V,u'\in V'\}$

Bipartite graph CA(S) :

The bipartite graph $CA(S)=(V,V',X)$, where $X=\{(u,v')/\,u\ and\ v\ are\ consecutively\ adjacent\ in\ S\}$

Bipartite graph CA⁺(S) :

The bipartite graph $CA^{+}(S)=(V,V',X)$, where $X=\{(u,v')/\,u\ and\ v\ are\ consecutively\ adjacent\ in\ S\}\cup\{(u,u')/\,u\in V,u'\in V'\}$

Bipartite graph VE(S) :

The bipartite graph $VE(S)=(V,X,Y)$, where V is vertex set and X is the set of edges of the semigraph S and $Y=\{(u,e)/\,u\in V\ \&\ e\in X\}$.

$C_{m,1}$ is a 3-uniform semigraph. The Bipartite graph A($C_{5,1}$), the Bipartite graph A⁺($C_{5,1}$), the Bipartite graph CA($C_{5,1}$), the Bipartite graph CA⁺($C_{5,1}$) and the Bipartite graph VE($C_{5,1}$) are given in the following Figures 2 –6 respectively.

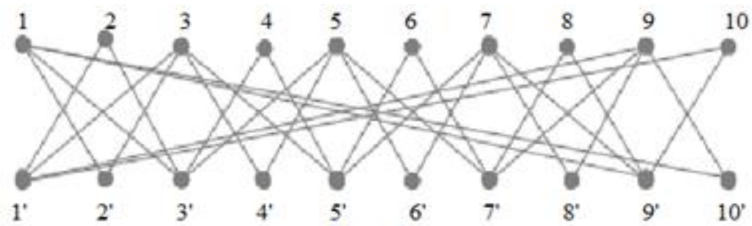

Figure 2

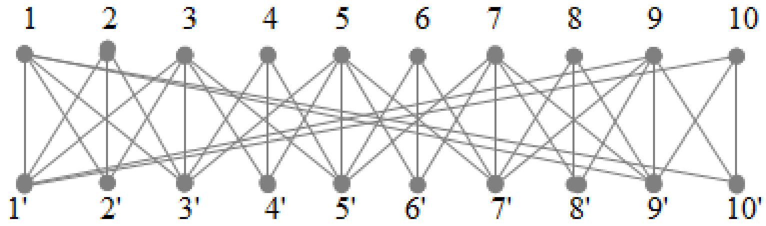

Figure 3

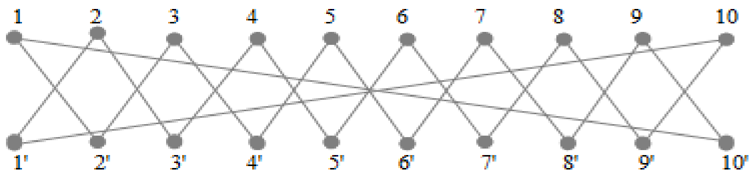

Figure 4

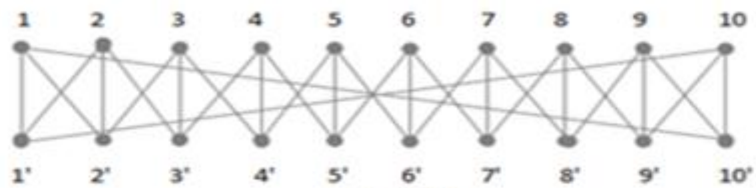

Figure 5

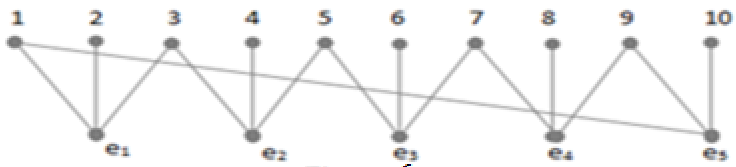

Figure 6

The Bipartite graph CA($C_{5,1}$) is the disjoint union of two cycles and which is a disconnected graph.

Theorem 2.1 : Let $C_{m,1}$ be the semigraph and let G be the Bipartite graph A($C_{m,1}$). Then $W(G) = 2m^3 + 8m^2 + 2m$, $PI(G) = 24m^2$, $Co - PI(G) = 4m(2m-2)$

Proof: Let $V(C_m) = \{v_1, v_2, ..., v_m\}$ and $E(C_m) = \{v_i v_{i+1} / i = 1 \text{ to } m-1\} \cup \{v_m v_1\}$ be the vertex set and edge set of the cycle graph C_m respectively. Let $U = V \cup V'$ *where* $V = \{v_1, v_2, ..., v_{2m}\}$, $V' = \{v_1', v_2', ..., v_{2m}'\}$ and $E = \{(u, v') / u \text{ and } v$ *belong to the same edge of the semigraph* $C_{m,1}\}$ be the vertex set and edge set of the graph G = Bipartite graph A($C_{m,1}$) respectively.

Wiener Index of G :

Case (i) : m is even

For any $u,v \in U(G)$, the following table gives the distance $d(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $d(u,v)$.

$d(u,v)$	1	2	3	4	5	…	$\frac{m-2}{2}$	$\frac{m}{2}$	$\frac{m+2}{2}$	$\frac{m+4}{2}$
the number of pairs of vertices with distance $d(u,v)$	$6m$	$14m$	$18m$	$16m$	$16m$	…	$16m$	$15m$	$8m$	m

$$W(G) = 6m\times1 + 14m\times2 + 18m\times3 + 16m\left[4+5+6+\ldots+\frac{m-2}{2}\right]$$
$$+15m\left(\frac{m}{2}\right) + 8m\left(\frac{m+2}{2}\right) + m\left(\frac{m+4}{2}\right)$$
$$= 2m^3 + 8m^2 + 2m$$

Case (ii) : m is odd

For any $u,v \in U(G)$, the following table gives the distance $d(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $d(u,v)$.

$d(u,v)$	1	2	3	4	5	…	$\frac{m-1}{2}$	$\frac{m+1}{2}$	$\frac{m+3}{2}$
the number of pairs of vertices with distance $d(u,v)$	$6m$	$14m$	$18m$	$16m$	$16m$	…	$16m$	$12m$	$8m$

$$W(G) = 6m\times1 + 14m\times2 + 18m\times3 + 16m\left[4+5+6+\ldots+\frac{m-1}{2}\right] +$$
$$12m\left(\frac{m+1}{2}\right) + 8m\left(\frac{m+3}{2}\right)$$
$$= 2m^3 + 8m^2 + 2m$$

PI of G : For any m,

$$PI(G) = \sum_{e=uv\in E(G)} \left[n_u^G(e) + n_v^G(e)\right] = |U(G)|\cdot|E(G)| = 4m\times6m = 24m^2.$$

Co - PI of G : For any edge $e = uv \in E(G)$, the following table gives the number of edges, $n_u^G(e)$ and $n_v^G(e)$.

Edge	Number of edges	$n_u^G(e)$	$n_v^G(e)$
$e = uv'$ if both u and v' *are either even or odd*	$2m$	$2m$	$2m$
$e = uv'$ if u *is even and* v' *is odd*	$2m$	$m+1$	$3m-1$
$e = uv'$ if u *is odd and* v' *is even*	$2m$	$3m-1$	$m+1$

For any m, $Co-PI(G) = \sum_{e=uv \in E(G)} \left| n_u^G(e) - n_v^G(e) \right| = 4m(2m-2)$.

Theorem 2.2 : Let $C_{m,1}$ be the semigraph and let G be the Bipartite graph $A^+(C_{m,1})$.
Then $W(G) = 2m^3 + 8m^2 - 2m$, $D(G) = 32m^3 - 20m^2 + 4m$,
$C(G) = 34m^3 - 12m^2 + 2m$, $PI(G) = 32m^2$ *and* $Co-PI(G) = 4m(2m-2)$.

Proof: Let $V(C_m) = \{v_1, v_2, ..., v_m\}$ and $E(C_m) = \{v_i v_{i+1} / i = 1 \text{ to } m-1\} \cup \{v_m v_1\}$ be the vertex set and edge set of the cycle graph C_m respectively. Let $U = V \cup V'$ *where* $V = \{v_1, v_2, ..., v_{2m}\}$, $V' = \{v_1', v_2', ..., v_{2m}'\}$ and $E = \{(u, v') / u \text{ and } v$ *belong to the same edge of the semigraph* $C_{m,1}\} \cup \{(u, u') / u \in V,\ u' \in V'\}$ be the vertex set and edge set of the graph G = Bipartite graph $A^+(C_{m,1})$ respectively.

Wiener Index of G :

Case (i) : m is even

For any $u, v \in U(G)$, the following table gives the distance $d(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $d(u,v)$

$d(u,v)$	1	2	3	4	5	…	$\frac{m-2}{2}$	$\frac{m}{2}$	$\frac{m+2}{2}$	$\frac{m+4}{2}$
the number of pairs of vertices with distance $d(u,v)$	$8m$	$14m$	$16m$	$16m$	$16m$	…	$16m$	$15m$	$8m$	m

$$W(G)=8m\times1+14m\times2+16m\left[3+4+5+6+...+\frac{m-2}{2}\right]$$
$$+15m\left(\frac{m}{2}\right)+8m\left(\frac{m+2}{2}\right)+m\left(\frac{m+4}{2}\right)$$
$$=2m^3+8m^2-2m$$

Case (ii) : m is odd

For any $u,v\in U(G)$, the following table gives the distance $d(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $d(u,v)$

$d(u,v)$	1	2	3	4	5	…	$\frac{m-1}{2}$	$\frac{m+1}{2}$	$\frac{m+3}{2}$
the number of pairs of vertices with distance $d(u,v)$	$8m$	$14m$	$16m$	$16m$	$16m$	…	$16m$	$12m$	$8m$

$$W(G)=8m\times1+14m\times2+16m\left[3+4+5+6+...+\frac{m-1}{2}\right]$$
$$+12m\left(\frac{m+1}{2}\right)+8m\left(\frac{m+3}{2}\right)$$
$$=2m^3+8m^2-2m$$

Detour Index of G :

For any $u,v\in U(G)$, the following table gives the distance $D(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $D(u,v)$

$D(u,v)$	$4m-2$	$4m-1$
the number of pairs of vertices with distance $D(u,v)$	$2m(2m-1)$	$4m^2$

For any m, $D(G)=2m(2m-1)(4m-2)+(4m-1)4m^2=32m^3-20m^2+4m$

Circular Index of G : For any m, $C(G)=W(G)+D(G)=34m^3-12m^2+2m.$

PI of G : For any m,

$$PI(G)=\sum_{e=uv\in E(G)}\left[n_u^G(e)+n_v^G(e)\right]=|U(G)|\cdot|E(G)|=4m\times8m=32m^2.$$

Co - PI of G :

For any edge $e=uv\in E(G)$, the following table gives the number of edges, $n_u^G(e)$ and $n_v^G(e)$.

Edge	Number of edges	$n_u^G(e)$	$n_v^G(e)$
$e = uv'$ if both u and v' *are either even or odd*	$2m$	$2m$	$2m$
$e = uv'$ if u *is even and* v' *is odd*	$2m$	$m+1$	$3m-1$
$e = uv'$ if u *is odd and* v' *is even*	$2m$	$3m-1$	$m+1$

For any m, $Co-PI(G) = \sum_{e=uv\in E(G)} \left|n_u^G(e) - n_v^G(e)\right| = 4m(2m-2)$.

Theorem 2.3 : Let $C_{m,1}$ be the semigraph and let G be the Bipartite graph CA$^+$($C_{m,1}$). Then $W(G) = 4m^3 + 4m^2$, $D(G) = 32m^3 - 20m^2 + 4m$, $C(G) = 36m^3 - 16m^2 + 4m$, $PI(G) = 24m^2$ & $Co-PI(G) = 0$.

Proof: Let $V(C_m) = \{v_1, v_2, ..., v_m\}$ and $E(C_m) = \{v_i v_{i+1} / i = 1 \text{ to } m-1\} \cup \{v_m v_1\}$ be the vertex set and edge set of the cycle graph C_m respectively. Let $U = V \cup V'$ *where* $V = \{v_1, v_2, ..., v_{2m}\}$, $V' = \{v_1', v_2', ..., v_{2m}'\}$ and $E = \{(u, v') / u \text{ and } v \text{ consecutively adjacent in the semigraph } C_{m,1}\} \cup \{(u, u') / u \in V,\ u' \in V'\}$ be the vertex set and edge set of the graph G = Bipartite graph CA$^+$($C_{m,1}$) respectively.

Wiener Index of G :

For any $u, v \in U(G)$, the following table gives the distance $d(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $d(u,v)$.

$d(u,v)$	1	2	3	4	…	$m-1$	m	$m+1$
the number of pairs of vertices with distance $d(u,v)$	$6m$	$8m$	$8m$	$8m$	…	$8m$	$6m$	$2m$

$$W(G) = 6m \times 1 + 8m\left[2 + 3 + 4 + ... + (m-1)\right] + 6m \times m + 2m \times (m+1)$$
$$= 4m^3 + 4m^2$$

Detour Index of G :

For any $u, v \in U(G)$, the following table gives the distance $D(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $d(u,v)$.

$D(u,v)$	$4m-2$	$4m-1$
the number of pairs of vertices with distance $D(u,v)$	$2m(2m-1)$	$4m^2$

For any m, $D(G) = 2m(2m-1)(4m-2) + (4m-1)4m^2 = 32m^3 - 20m^2 + 4m$

Circular Index of G : For any m, $C(G) = W(G) + D(G) = 36m^3 - 16m^2 + 4m.$

PI of G : For any m, $PI(G) = |U(G)| \cdot |E(G)| = 4m \times 6m = 24m^2.$

Co - PI of G :

For any edge $e = uv \in E(G)$, the following table gives the number of edges, $n_u^G(e)$ and $n_v^G(e)$.

Edge	Number of edges	$n_u^G(e)$	$n_v^G(e)$
$e = uv'$	$6m$	$2m$	$2m$

For any m, $Co-PI(G) = \sum_{e=uv\in E(G)} |n_u^G(e) - n_v^G(e)| = 0.$

Theorem 2.4 : Let $C_{m,1}$ be the semigraph and let G be the Bipartite graph VE($C_{m,1}$).

$$W(G) = \begin{cases} \frac{1}{4}(9m^3 + 12m^2 - 4m) & if\ m\ is\ even \\ \frac{1}{4}(9m^3 + 12m^2 - 5m) & if\ m\ is\ odd \end{cases}$$

$$D(G) = \begin{cases} \frac{1}{4}(27m^3 - 8m^2 - 4m) & if\ m\ is\ even \\ \frac{1}{4}(27m^3 - 8m^2 - 3m) & if\ m\ is\ odd \end{cases}$$

$$C(G) = 9m^3 + m^2 - 2m,\ \ PI(G) = 9m^2\ \ and\ Co-PI(G) = \begin{cases} 3m^2 - 2m & if\ \ m\ is\ even \\ 3m^2 & if\ \ m\ is\ odd \end{cases}$$

Proof: Let $V(C_m) = \{v_1, v_2, ..., v_m\}$ and $E(C_m) = \{v_i v_{i+1} / i = 1\ to\ m-1\} \cup \{v_m v_1\}$ be the vertex set and edge set of the cycle graph C_m respectively. Let $U = V \cup V'$ *where* $V = \{v_1, v_2, ..., v_{2m}\}$, $V' = \{e_1, e_2, ..., e_m\}$ and $E = \{(e_i, v_j) / 1 \le i \le m-1,\ j = 2i-1,\ 2i,\ 2i+1\} \cup \{(e_m, j) / j = 2m-1,\ 2m,\ 1\}$ be the vertex set and edge set of the graph G = Bipartite graph VE($C_{m,1}$) respectively.

Wiener Index of G:

Case (i) : m is even

For any $u,v \in U(G)$, the following table gives the distance $d(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $d(u,v)$

$d(u,v)$	1	2	3	4	…	$m-1$	m	$m+1$	$m+2$
the number of pairs of vertices with distance $d(u,v)$	$3m$	$4m$	$4m$	$5m$	…	$4m$	$4m$	m	$\frac{m}{2}$

$$W(G) = 3m \times 1 + 4m \times 2 + 5m[4+6+...+m-2]$$
$$+4m[3+5+...+m-1] + 4m \times m + m \times (m+1) + \frac{m}{2} \times (m+2)$$
$$= \frac{1}{4}(9m^3 + 12m^2 - 4m)$$

Case (ii) : m is odd

For any $u,v \in U(G)$, the following table gives the distance $d(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $d(u,v)$.

$d(u,v)$	1	2	3	4	5	…	$m-1$	m	$m+1$
the number of pairs of vertices with distance $d(u,v)$	$3m$	$4m$	$4m$	$5m$	$4m$	…	$5m$	$3m$	$2m$

$$W(G) = 3m \times 1 + 4m \times 2 + 5m[4+6+...+m-1]$$
$$+4m[3+5+...+m-2] + 3m \times m + 2m \times (m+1)$$
$$= \frac{1}{4}(9m^3 + 12m^2 - 5m)$$

Detour Index of G:

Case (i) : m is even

For any $u,v \in U(G)$, the following table gives the distance $D(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $D(u,v)$

$D(u,v)$	1	m	$m+1$	$m+2$	$m+3$	$m+4$	…	$2m-2$	$2m-1$	$2m$
the number of pairs of vertices with distance $D(u,v)$	m	m	$3m$	$\frac{9m}{2}$	$4m$	$5m$	…	$5m$	$4m$	$3m$

$$D(G) = m\times 1 + m\times m + (m+1)\times 3m + (m+2)\times \frac{9m}{2} + 4m[(m+3)+(m+5)+\ldots+(2m-1)] + 5m[(m+4)+(m+6)+\ldots+(2m-2)] + 3m\times 2m$$
$$= \frac{1}{4}(27m^3 - 8m^2 - 4m)$$

Case (ii) : m is odd

For any $u,v \in U(G)$, the following table gives the distance $D(u,v)$ between the vertices u *and* v and the number of pairs of vertices with distance $D(u,v)$

$D(u,v)$	1	m	$m+1$	$m+2$	$m+3$	…	$2m-2$	$2m-1$	$2m$
the number of pairs of vertices with distance $D(u,v)$	m	m	$3m$	$4m$	$5m$	…	$5m$	$4m$	$3m$

$$D(G) = m\times 1 + m\times m + (m+1)\times 3m + 4m[(m+2)+(m+4)+\ldots+(2m-1)] + 5m[(m+3)+(m+5)+\ldots+(2m-2)] + 3m\times 2m$$
$$= \frac{1}{4}(27m^3 - 8m^2 - 3m)$$

PI of G: For any m, $PI(G) = |U(G)|\cdot|E(G)| = 3m\times 3m = 9m^2$.

Co-PI of G :

Case (i) : m is even

For any edge $e = ue_i \in E(G)$, the following table gives the number of edges, $n_u^G(e)$ and $n_{e_i}^G(e)$.

Edge		Number of edges	$n_u^G(e)$	$n_v^G(e)$
$e = ue_i$	*u is even*	m	1	$3m-1$
	u is odd	$2m$	$\frac{m}{2}$	$\frac{m}{2}$

For any m, $Co-PI(G) = \sum_{e=ue_i\in E(G)} \left|n_u^G(e) - n_{e_i}^G(e)\right| = m(3m-2)$.

Case (ii) : m is odd

For any edge $e = ue_i \in E(G)$, the following table gives the number of edges, $n_u^G(e)$ and $n_{e_i}^G(e)$.

Edge		Number of edges	$n_u^G(e)$	$n_v^G(e)$
$e = ue_i$	*u is even*	m	1	$3m-1$
	u is odd	$2m$	$\frac{m-1}{2}$	$\frac{m+1}{2}$

For any m, $Co-PI(G) = \sum_{e=ue_i \in E(G)} \left| n_u^G(e) - n_{e_i}^G(e) \right| = m(3m-2) + 2m = 3m^2$.

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