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ECCENTRICITY BASED TOPOLOGICAL INDICES OF SOME GRAPHS

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ABSTRACT. Topological indices are real numbers that are presented as graph parameters introduced during studies conducted on the molecular graphs in chemistry and can describe some physical and chemical properties of molecules. In this paper we compute eccentricity based topological indices for crown graph, gear graph, friendship graph, helm graph flower graph and their line graphs.

Keywords: Distance, eccentricity, degree, line graph, topological index.

AMS Subject Classification: 05C90, 05C35, 05C12.

1. INTRODUCTION

All the graphs $G = (V, E)$ considered in this paper are simple, undirected and connected graphs. For any vertices $u, v \in V(G)$, the distance $d(u, v)$ is defined as the length of any shortest path connecting u and v in G. For any vertex v in G, the degree $(d_v\ )$ of v is the number of edges incident with v in G and the eccentricity (e_v) of v is the largest distance between v and any other vertex of G. The line graph $L(G)$ of a graph G is the graph whose vertices are the edges of G, two vertices e and f are adjacent in $L(G)$ if and only if they have a common end vertex in G[2].

A topological index is a numerical parameter mathematically derived from the graph structure. It is a graph invariant, thus it does not depend on the labelling or pictorial representation of the graph. The topological indices of molecular graphs are widely used for establishing correlations between the structure of a molecular compound and its physicochemical properties or biological activity (e.g., pharmacology)[6]. There exist several types of such indices. In Table 1, we describe some eccentricity based topological indices.

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Sl.No.	Introduced by	Index Name	Notation	Formula
1	Sharma et al.[13]	Eccentric connectivity index	$\xi(G)$	$\sum_{v\in V(G)} d_v e_v$
2	M. Alaeiyan et al.[8]	Eccentric connectivity polynomial	$ECP(G,x)$	$\sum_{v\in V(G)} d_v x^{e_v}$
3	R. Farooq et al. [12]	Total eccentricity index	$\zeta(G)$	$\sum_{v\in V(G)} e_v$
4	F. Bukley et al.[3]	Average eccentricity	$avec(G)$	$\frac{1}{n}\sum_{v\in V(G)} e_v$
5	D. Vukičević et al.[15] and M. Ghorbani et al.[4]	First Zagreb eccentric index	$M_1^*(G)$	$\sum_{uv\in E(G)} [e_u + e_v]$
		Second Zagreb eccentric index	$M_1^{**}(G)$	$\sum_{v\in V(G)} e_v^2$
		Third Zagreb eccentric index	$M_2^*(G)$	$\sum_{uv\in E(G)} e_u e_v$
6	M. Ghorbani et al. [5]	Fourth Geometric-arithmetic index	$GA_4(G)$	$\sum_{uv\in E(G)} \frac{2\sqrt{e_u e_v}}{e_u + e_v}$
7	Padmapriya P. et al.[10]	First Zagreb degree eccentricity index	$DE_1(G)$	$\sum_{v\in V(G)} [e_v + d_v]^2$
		Second Zagreb degree eccentricity index	$DE_2(G)$	$\sum_{uv\in E(G)} (e_u + d_u)(e_v + d_v)$

Table 1: Eccentricity based topological indices

The aim of this paper is to compute the above described eccentricity based topological indices for crown graph, gear graph, friendship graph, helm graph flower graph and their line graphs.

Remark 1.1. [7] $\xi(G) = \sum_{v\in V(G)} d_v e_v = \sum_{uv\in E(G)} [e_u + e_v]$

2. Crown Graph

The graph $CW_n = C_n \circ K_1$ is called a crown graph[11]. The graph CW_8 and its line graph $L(CW_8)$ are shown in Fig. 1.

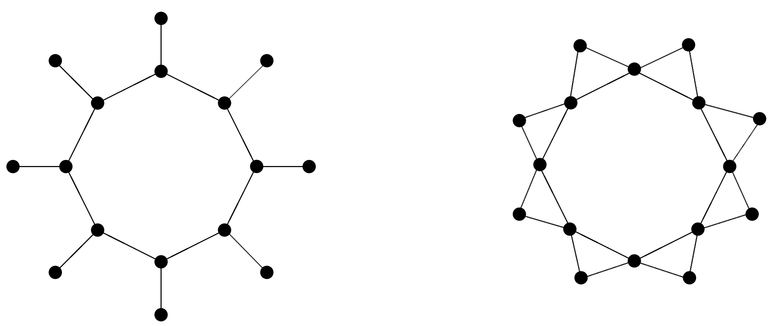

Fig. 1: The crown graph CW_8 and its line graph $L(CW_8)$

Number of vertices	d_u	e_u	Number of edges	(d_u, d_v)	(e_u, e_v)
n	1	$\frac{n}{2}+2$	n	(3, 3)	$\left(\frac{n}{2}+1, \frac{n}{2}+1\right)$
n	3	$\frac{n}{2}+1$	n	(1, 3)	$\left(\frac{n}{2}+2, \frac{n}{2}+1\right)$

Table 2: Vertex and edge partition of CW_n, if n is even

Number of vertices	d_u	e_u	Number of edges	(d_u, d_v)	(e_u, e_v)
n	1	$\frac{n-1}{2}+2$	n	(3, 3)	$\left(\frac{n-1}{2}+1, \frac{n-1}{2}+1\right)$
n	3	$\frac{n-1}{2}+1$	n	(1, 3)	$\left(\frac{n-1}{2}+2, \frac{n-1}{2}+1\right)$

Table 3: Vertex and edge partition of CW_n, if n is odd

Number of vertices	d_u	e_u	Number of edges	(d_u, d_v)	(e_u, e_v)
n	2	$\frac{n}{2}+1$	2n	(2, 4)	$\left(\frac{n}{2}+1, \frac{n}{2}\right)$
n	4	$\frac{n}{2}$	n	(4, 4)	$\left(\frac{n}{2}, \frac{n}{2}\right)$

Table 4: Vertex and edge partition of $L(CW_n)$, if n is even

Number of vertices	d_u	e_u	Number of edges	(d_u, d_v)	(e_u, e_v)
n	2	$\frac{n+1}{2}$	2n	(2, 4)	$\left(\frac{n+1}{2}, \frac{n+1}{2}\right)$
n	4	$\frac{n+1}{2}$	n	(4, 4)	$\left(\frac{n+1}{2}, \frac{n+1}{2}\right)$

Table 5: Vertex and edge partition of $L(CW_n)$, if n is odd

Theorem 2.1. *Let $G = CW_n$ be the crown graph. Then*
(i) If n is even

(1) $\xi(G) = 2n^2 + 5n$
(2) $ECP(G, x) = nx^{\frac{n+4}{2}} + 3nx^{\frac{n+2}{2}}$
(3) $\zeta(G) = n^2 + 3n$
(4) $avec(G) = \frac{1}{2}(n + 3)$
(5) $M_1^*(G) = 2n^2 + 5n$
(6) $M_1^{**}(G) = \frac{n^3}{2} + 3n^2 + 5n$
(7) $M_2^*(G) = \frac{n}{2}[n^2 + 7n + 6]$
(8) $GA_4(G) = n + \frac{n\sqrt{n^2 + 6n + 8}}{n + 3}$
(9) $DE_1(G) = \frac{n^3}{2} + 7n^2 + 25n$
(10) $DE_2(G) = \frac{n^3}{2} + \frac{15}{2}n^2 + 28n$

(ii) If n is odd

(1) $\xi(G) = 2n^2 + 3n$
(2) $ECP(G, x) = nx^{\frac{n+3}{2}} + 3nx^{\frac{n+1}{2}}$
(3) $\zeta(G) = n^2 + 2n$

(4) $avec(G) = \frac{1}{2}(n+2)$
(5) $M_1^*(G) = 2n^2 + 3n$
(6) $M_1^{**}(G) = \frac{n^3}{2} + 2n^2 + \frac{5}{2}n$
(7) $M_2^*(G) = \frac{n}{2}[n^2 + 3n + 2]$
(8) $GA_4(G) = n + \frac{n\sqrt{n^2+4n+3}}{n+2}$
(9) $DE_1(G) = \frac{n^3}{2} + 6n^2 + \frac{37}{2}n$
(10) $DE_2(G) = \frac{n^3}{2} + \frac{13}{2}n^2 + 24n$

Proof. The crown graph has $2n$ vertices and $2n$ edges. Based on the degree and eccentricity of vertices of CW_n we partition $V(CW_n)$ into subsets and also we partition $E(CW_n)$ based on the degree and eccentricity of end vertices of edges in CW_n as shown in Tables 2 and 3. Using the information in these tables, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

Theorem 2.2. *Let $H = L(CW_n)$ be the line graph of crown graph CW_n. Then*
(i) If n is even

(1) $\xi(H) = n(3n+2)$
(2) $ECP(H,x) = 2n[x^{\frac{n+2}{2}} + 2x^{\frac{n}{2}}]$
(3) $\zeta(H) = n(n+1)$
(4) $avec(H) = \frac{1}{2}(n+1)$
(5) $M_1^*(H) = n(3n+2)$
(6) $M_1^{**}(H) = n\left[\frac{n^2}{2} + n + 1\right]$
(7) $M_2^*(H) = n^2\left[\frac{3}{2}n + 1\right]$
(8) $GA_4(H) = n + \frac{2n\sqrt{n(n+2)}}{n+1}$
(9) $DE_1(H) = \frac{n^3}{2} + 7n^2 + 25n$
(10) $DE_2(H) = \frac{3}{4}n^3 + 11n^2 + 40n$

(ii) If n is odd

(1) $\xi(H) = 3n(n+1)$
(2) $ECP(H,x) = 6nx^{\frac{n+1}{2}}$
(3) $\zeta(H) = n(n+1)$
(4) $avec(H) = \frac{1}{2}(n+1)$
(5) $M_1^*(H) = 3n(n+1)$
(6) $M_1^{**}(H) = n\left[\frac{n^2}{2} + n + \frac{1}{2}\right]$
(7) $M_2^*(H) = \frac{3n}{4}\left[n^2 + 2n + 1\right]$
(8) $GA_4(H) = 3n$

(9) $DE_1(H) = \frac{n^3}{2} + 7n^2 + \frac{53}{2}n$

(10) $DE_2(H) = \frac{3}{4}n^3 + \frac{23}{2}n^2 + \frac{179}{4}n$

Proof. The line graph H of crown graph CW_n has $2n$ vertices and $3n$ edges. Based on the degree and eccentricity of vertices of H we partition $V(H)$ into subsets and also we partition $E(H)$ based on the degree and eccentricity of end vertices of edges in $L(H)$ as shown in Tables 4 and 5. Using the information in these tables, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

3. Gear graph

The gear graph G_n is obtained from the wheel W_{n+1} by adding a vertex between every pair of adjacent vertices of the cycle C_n[1]. The graph G_6 and its line graph $L(G_6)$ are shown in Fig. 2.

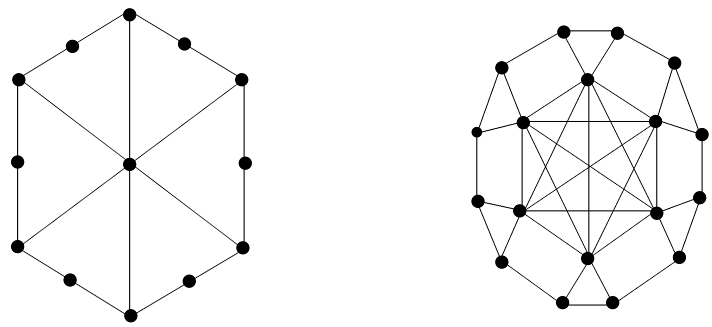

Fig. 2: The graph G_6 and its line graph $L(G_6)$

Number of vertices	d_u	e_u
n	3	3
n	2	4
1	n	2

Table 6: Vertex partition of G_n

Number of edges	(d_u, d_v)	(e_u, e_v)
2n	(2, 3)	(4, 3)
n	(3, n)	(3, 2)

Table 7: Edge partition of G_n

Number of vertices	d_u	e_u
n	n+1	2
2n	3	3

Table 8: Vertex partition of $L(G_n)$

Number of edges	(d_u, d_v)	(e_u, e_v)
2n	(3, 3)	(3, 3)
2n	(3, n+1)	(3, 2)
$\frac{n(n-1)}{2}$	(n+1, n+1)	(2, 2)

Table 9: Edge partition of $L(G_n)$

Theorem 3.1. *Let $G = G_n$ be the gear graph. Then*

(1) $\xi(G) = 19n$
(2) $ECP(G, x) = n[2x^4 + 3x^3 + x^2]$
(3) $\zeta(G) = 7n + 2$
(4) $avec(G) = 2 + \dfrac{3n}{2n+1}$
(5) $M_1^*(G) = 19n$
(6) $M_1^{**}(G) = 25n + 4$
(7) $M_2^*(G) = 30n$
(8) $GA_4(G) = 2n\left[\dfrac{4\sqrt{3}}{7} + \dfrac{\sqrt{6}}{5}\right]$
(9) $DE_1(G) = n^2 + 76n + 4$
(10) $DE_2(G) = 6n(n + 14)$

Proof. The gear graph has $2n + 1$ vertices and $3n$ edges. Based on the degree and eccentricity of vertices of G_n we partition $V(G_n)$ into subsets as shown in Table 6 and also we partition $E(G_n)$ based on the degree and eccentricity of end vertices of edges in G_n as shown in Table 7. Using the information in these tables, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

Theorem 3.2. *Let $H = L(G_n)$ be the line graph of gear graph G_n. Then*

(1) $\xi(H) = 2n(n + 10)$
(2) $ECP(H, x) = n[6x^3 + (n + 1)x^2]$
(3) $\zeta(H) = 8n$
(4) $avec(H) = \dfrac{8}{3}$
(5) $M_1^*(H) = 2n(n + 10)$
(6) $M_1^{**}(H) = 22n$
(7) $M_2^*(H) = 2n(n + 14)$
(8) $GA_4(H) = \dfrac{n^2}{2} + \left(\dfrac{15 + 8\sqrt{6}}{10}\right)n$
(9) $DE_1(H) = n^3 + 6n^2 + 81n$
(10) $DE_2(H) = \dfrac{n}{2}[n^3 + 5n^2 + 27n + 129]$

Proof. The line graph H of gear graph G_n has $3n$ vertices and $\dfrac{n^2 + 7n}{2}$ edges. Based on the degree and eccentricity of vertices of H we partition $V(H)$ into subsets as shown in Table 8 and also we partition $E(H)$ based on the degree and eccentricity of end vertices of edges in H as shown in Table 9. Using the information in these tables, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

4. Friendship Graph

Let C_t^n denote the graph obtained by identifying one vertex of each of n copies of C_t, $t \geq 3$. The graph C_3^n, $n \geq 2$ is called friendship graph. The graph C_3^4 and its line graph $L(C_3^4)$ are shown in Fig. 3.

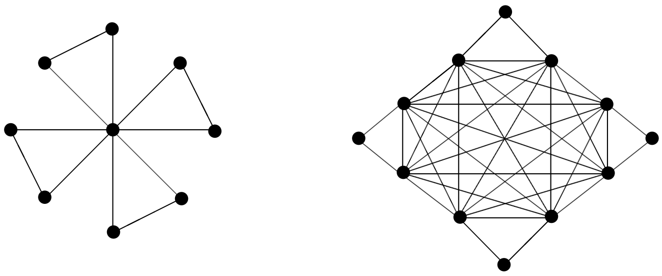

Fig. 3: The friendship graph C_3^4 and its line graph $L(C_3^4)$

Number of vertices	d_u	e_u	Number of edges	(d_u, d_v)	(e_u, e_v)
2n	2	2	2n	(2, 2n)	(2, 1)
1	2n	1	n	(2, 2)	(2, 2)

Table 10: Vertex and edge partition of C_3^n

Number of vertices	d_u	e_u	Number of edges	(d_u, d_v)	(e_u, e_v)
2n	2n	2	2n	(2, 2n)	(3, 2)
n	2	3	n(2n-1)	(2n, 2n)	(2, 2)

Table 11: Vertex and edge partition of $L(C_3^n)$

Theorem 4.1. *Let $G = C_3^n$ be the friendship graph. Then*

(1) $\xi(G) = 10n$
(2) $ECP(G, x) = 2n(2x^2 + x)$
(3) $\zeta(G) = 4n + 1$
(4) $avec(G) = \dfrac{4n+1}{2n+1}$
(5) $M_1^*(G) = 10n$
(6) $M_1^{**}(G) = 8n + 1$
(7) $M_2^*(G) = 8n$
(8) $GA_4(G) = n\left(\dfrac{4\sqrt{2}}{3} + 1\right)$
(9) $DE_1(G) = 4n^2 + 12n + 1$
(10) $DE_2(G) = 8n(2n + 3)$

Proof. The friendship graph has $2n + 1$ vertices and $3n$ edges. Based on the degree and eccentricity of vertices of C_3^n we partition $V(C_3^n)$ into subsets and also we partition $E(C_3^n)$ based on the degree and eccentricity of end vertices of edges in C_3^n as shown in Table 10. Using the information in Table 10, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

Theorem 4.2. *Let $H = L(C_3^n)$ be the line graph of Friendship graph C_3^n. Then*

(1) $\xi(H) = 2n(4n + 3)$
(2) $ECP(H, x) = 2n[x^3 + 2nx^2]$
(3) $\zeta(H) = 7n$
(4) $avec(H) = \dfrac{7}{3}$
(5) $M_1^*(H) = 2n(4n + 3)$
(6) $M_1^{**}(H) = 17n$
(7) $M_2^*(H) = 8n(n + 1)$

(8) $GA_4(H) = 2n^2 + \left(\frac{4\sqrt{6}-5}{5}\right)n$

(9) $DE_1(H) = 8n^3 + 16n^2 + 33n$

(10) $DE_2(H) = 4n[2n^3 + 3n^2 + 5n + 4]$

Proof. The line graph H of friendship graph C_3^n has $3n$ vertices and $n(2n+1)$ edges. Based on the degree and eccentricity of vertices of H we partition $V(H)$ into subsets and also we partition $E(H)$ based on the degree and eccentricity of end vertices of edges in h as shown in table 11. Using the information in Table 11, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

5. Helm Graph

The Helm Graph H_n is the graph obtained from a wheel graph W_{n+1} by adjoining a pendant edge at each vertex of the cycle[14]. The graph H_6 and its line graph $L(H_6)$ are shown in Fig. 4.

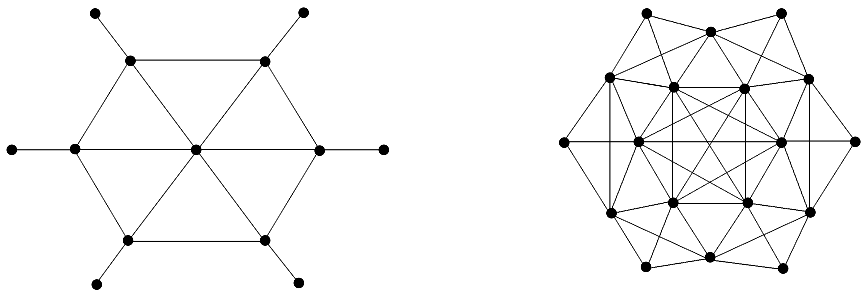

Fig. 4: The helm graph H_6 and its line graph $L(H_6)$

Number of vertices	d_u	e_u
n	4	3
n	1	4
1	n	2

Table 12: Vertex partition of H_n

Number of edges	(d_u, d_v)	(e_u, e_v)
n	(1, 4)	(4, 3)
n	(4, 4)	(3, 3)
n	(n, 4)	(2, 3)

Table 13: Edge partition of H_n

Number of vertices	d_u	e_u
n	n+2	2
n	6	3
n	3	3

Table 14: Vertex partition of $L(H_n)$

Number of edges	(d_u, d_v)	(e_u, e_v)
$\frac{n(n-1)}{2}$	(n+2, n+2)	(2, 2)
2n	(n+2, 6)	(2, 3)
2n	(6, 3)	(3, 3)
n	(n+2, 3)	(2, 3)
n	(6, 6)	(3, 3)

Table 15: Edge partition of $L(H_n)$

Theorem 5.1. *Let $G = H_n$ be the helm graph. Then*

(1) $\xi(G) = 18n$
(2) $ECP(G, x) = n[x^4 + 4x^3 + x^2]$
(3) $\zeta(G) = 7n + 2$
(4) $avec(G) = \frac{7n + 2}{2n + 1}$
(5) $M_1^*(G) = 18n$
(6) $M_1^{**}(G) = 25n + 4$
(7) $M_2^*(G) = 27n$
(8) $GA_4(G) = n\left[1 + \frac{4\sqrt{3}}{7} + \frac{2\sqrt{6}}{5}\right]$
(9) $DE_1(G) = n^2 + 78n + 4$
(10) $DE_2(G) = 7n(n + 14)$

Proof. The helm graph has $2n + 1$ vertices and $3n$ edges. Based on the degree and eccentricity of vertices of H_n we partition $V(H_n)$ into subsets as shown in Table 12 and also we partition $E(H_n)$ based on the degree and eccentricity of end vertices of edges in H_n as shown in Table 13. Using the information in these tables, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

Theorem 5.2. *Let $H = L(H_n)$ be the line graph of helm graph H_n. Then*

(1) $\xi(H) = n(2n + 31)$
(2) $ECP(H, x) = n[9x^3 + (n + 2)x^2]$
(3) $\zeta(H) = 8n$
(4) $avec(H) = \frac{8}{3}$
(5) $M_1^*(H) = n(2n + 31)$
(6) $M_1^{**}(H) = 22n$
(7) $M_2^*(H) = n(2n + 43)$
(8) $GA_4(H) = n\left[\frac{n + 5}{2} + \frac{6\sqrt{6}}{5}\right]$
(9) $DE_1(H) = n^3 + 8n^2 + 133n$
(10) $DE_2(H) = \frac{n^3}{2}(n + 9) + 36n^2 + 293n$

Proof. The line graph H of helm graph H_n has $3n$ vertices and $\frac{n^2 + 11n}{2}$ edges. Based on the degree and eccentricity of vertices of H we partition $V(H)$ into subsets as shown in Table 14 and also we partition $E(H)$ based on the degree and eccentricity of end vertices of edges in H as shown in Table 15. Using the information in these tables, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

6. Flower Graph

A flower graph F_n is the graph obtained from a helm graph by joining each pendant vertex to the central vertex of the helm graph[9]. The graph F_6 and its line graph $L(F_6)$ are shown in Fig. 5.

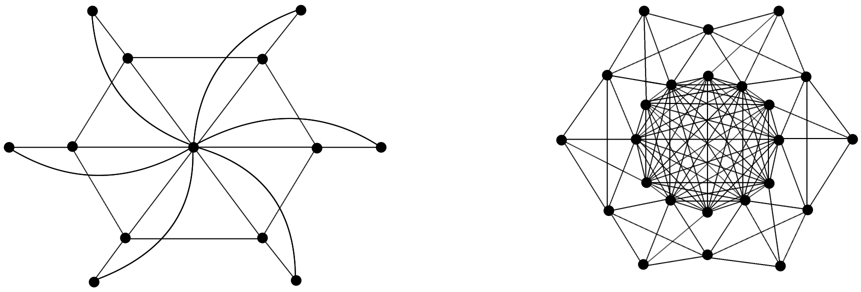

Fig. 5: The flower graph F_6 and its line graph $L(F_6)$

Number of vertices	d_u	e_u
n	4	2
n	2	2
1	2n	1

Table 16: Vertex partition of F_n

Number of edges	(d_u, d_v)	(e_u, e_v)
n	(4, 4)	(2, 2)
n	(2n, 4)	(1, 2)
n	(4, 2)	(2, 2)
n	(2n, 2)	(1, 2)

Table 17: Edge partition of F_n

Number of vertices	d_u	e_u
n	2n+2	2
n	2n	2
n	4	3
n	6	3

Table 18: Vertex partition of $L(F_n)$

Number of edges	(d_u, d_v)	(e_u, e_v)
$\frac{n(n-1)}{2}$	(2n, 2n)	(2, 2)
$\frac{n(n-1)}{2}$	(2n+2, 2n+2)	(2, 2)
n^2	(2n, 2n+2)	(2, 2)
n	(2n+2, 4)	(2, 3)
2n	(2n+2, 6)	(2, 3)
n	(2n, 4)	(2, 3)
2n	(4, 6)	(3, 3)
n	(6, 6)	(3, 3)

Table 19: Edge partition of $L(F_n)$

Theorem 6.1. *Let $G = F_n$ be the flower graph. Then*

(1) $\xi(G) = 14n$
(2) $ECP(G, x) = 2n[3x^2 + x]$
(3) $\zeta(G) = 4n + 1$
(4) $avec(G) = \frac{4n+1}{2n+1}$
(5) $M_1^*(G) = 14n$
(6) $M_1^{**}(G) = 8n + 1$

(7) $M_2^*(G) = 12n$

(8) $GA_4(G) = 2n\left[1 + \frac{2\sqrt{2}}{3}\right]$

(9) $DE_1(G) = 4n^2 + 56n + 1$

(10) $DE_2(G) = 10n(2n + 7)$

Proof. The flower graph has $2n + 1$ vertices and $4n$ edges. Based on the degree and eccentricity of vertices of F_n we partition $V(F_n)$ into subsets as shown in Table 16 and also we partition $E(F_n)$ based on the degree and eccentricity of end vertices of edges in F_n as shown in Table 17. Using the information in these tables, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

Theorem 6.2. *Let $H = L(F_n)$ be the line graph of flower graph F_n. Then*

(1) $\xi(H) = 2n(4n + 17)$

(2) $ECP(H, x) = 2n[5x^3(2n + 1)x^2]$

(3) $\zeta(H) = 10n$

(4) $avec(H) = \frac{5}{2}$

(5) $M_1^*(H) = 2n(4n + 17)$

(6) $M_1^{**}(H) = 26n$

(7) $M_2^*(H) = n(8n + 47)$

(8) $GA_4(H) = 2n\left[(n + 1) + \frac{4\sqrt{6}}{5}\right]$

(9) $DE_1(H) = n[8n^2 + 24n + 150]$

(10) $DE_2(H) = 8n^4 + 20n^3 + 70n^2 + 311n$

Proof. The line graph H of flower graph F_n has $4n$ vertices and $2n^2 + 6n$ edges. Based on the degree and eccentricity of vertices of H we partition $V(H)$ into subsets as shown in Table 18 and also we partition $E(H)$ based on the degree and eccentricity of end vertices of edges in H as shown in Table 19. Using the information in these tables, formulae from Table 1 and by Remark 1.1 we obtain the desired results. □

Observation 6.3. *The average eccentricity of line graph of gear graph, friendship graph, helm graph and flower graph is constant.*

7. Conclusions

In this paper eccentricity based topological indices for crown graph, gear graph, friendship graph, helm graph flower graph and their line graphs are computed.

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