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Research Article

Characterizing Graphs via Edge Geodetic Domination Number

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Abstract. Dominance in graphs is the crucial aspect of graph theory that has been thoroughly examined. Consider a graph $G_1(V_1,E_1)$ with $S \subseteq V_1$ in such a way that at least one vertex in the set is adjacent to the vertices that do not belong to the set then S is said to be the dominating set. In other words, it can be said that the set of vertices belonging to S and S' has at least a single neighbor in each other. Any set $A \subseteq G_1$ having all edges of G comprised in a geodesic uniting a pair of vertices in A is claimed to be an EG-set of G_1. The EG-number, indicated by the symbol $g_e(G)$, is the lowest order of its EG-set. A g_e-set of G or EG-basis of G, is any EG-set of order $g_e(G)$. If a collection of vertices D in G is together an EG-set and a dominant set then D is considered an EG-dominating set. The EG-dominance number of the EG-dominating set is its minimum cardinal number represented as $\gamma_{ge}(G)$. With this work, we explore the EG-dominance number of varied graphs namely antiprism graph A_n, alternate pentagonal snake $A(PS_n)$, Bistar graph, ladder graph, jewel graph and Helm graph.

Keywords. Edge geodetic dominating set, Edge geodetic dominance number, Antiprism graph alternate pentagonal snake graph, Bistar graph, Ladder graph

Mathematics Subject Classification (2020). 05C69, 05C76

1. Introduction

In this study, every graph taken into consideration is connected, simple, finite, non-trivial and undirected. A graph is a combination of vertices and edges and the degree of each vertex indicates how many edges are related to it. The shortest $u'-v'$ path and $d(u',v')$ in a connected graph are identical. The term $u'-v'$ geodesic refers to a $u'-v'$ path of length $d(u',v')$. The greatest separation between a vertex v_1 in G_1 and a different vertex is the eccentricity of the vertex v_1 and the term radius of G_1 i.e., $r(G_1)$ is referred to as the lowest eccentricity among the vertices of G_1 and the term diameter of G_1 i.e., diam(G_1) is the highest eccentricity among the vertices of G_1. Any collection $S \subseteq G_1$ in order that each vertex of G_1 is enclosed in a geodesic connecting a pair of vertices is called a geodetic set of G_1 and the least number of elements in the set is known as the geodetic number (Stalin and John [11]).

The collection of vertices next to a vertex, $N(v_1) = \{w_1 \in V_1 : v_1w_1 \in E_1\}$ makes up its open neighborhood $N(v_1)$ and the set of vertices that makes up its closed neighborhood is $N[v_1] = N(v_1) \cup \{v_1\}$ (Hansberg and Volkmann [5], and Stalin and John [11]). When $S \subseteq V_1$, a vertex $v_1 \in S$ is referred to as an isolate of S if $N(v_1) \subseteq V_1 - S$ and an enclave of S if $N[v_1] \subseteq S$. If a collection has no enclave, it is referred to as enclaveless. A status in a social network graph is a collection S of vertices possesses the characteristic that for any pair of vertices $u_1, v_1 \in S, N(u_1) \bigcap V_1 - S = N(v_1) \cap V_1 - S$ that is, in $V_1 - S$ the dominated collection of vertices by u_1 is identical to the dominated collection of vertices by v_1. Consequently, it is expected that every status must contain at least two vertices and in exterior of the status, the identical collection of vertices is dominated by every vertex in a status (Stalin and John [11]). In a graph G, if the subgraph induced by neighbor of v_1 is complete then the vertex v_1 is considered an extreme vertex and the collection of all the extreme vertices is represented as Ext(G). If a connected graph has a neighbor say u', with $N[v'] \subseteq N[u']$ then u' is examined as the semi-extreme vertex and the collection of these vertices is represented as $S_e(G)$ (Haynes *et al*. [6]). A collection $P \subseteq V(G)$ is an EG-set of G if all the edges are contained in a geodesic that connects a pair of vertices in P and the minimal order of its EG-set is referred to as the EG-number $g_e(G)$ and an EG-basis of G or a g_e-set of G is any EG-set of order $g_e(G)$ (Asdain *et al*. [1], Escuadro *et al*. [4], and Hansberg and Volkmann [5]). Initially, the notion of dominance number was introduced by C. Berge [2] in 1958 and this number also referred as the '*co-efficient of external stability*', Furthermore, in 2010, Hansberg and Volkmann [5] introduced the notion of geodetic dominance number of a graph and in 2016, Sudhahar *et al*. [12] introduced the concept of EG-domination number. If a collection of vertices D in G is both an EG-set and a dominant set then D is considered an EG-dominant set and the least number of vertices in the collection is mentioned as the EG-dominance number. The term 'γ_g*-set*' refers to a geodetic dominant set of size $\gamma_g(G)$. A collection of vertices S in a connected graph G satisfying the properties of edge geodetic and dominance is specified as EG-dominant set. The EG-dominance number represented by $\gamma_{ge}(G)$, indicates the minimal cardinal number of an EG-dominant set of G and the term γ_{ge}-set is used to describe an EG-dominant set of size $\gamma_{ge}(G)$ (Santhakumaran and John [10], Stalin and John [11], and Sudhahar *et al*. [12]).

2. Preliminaries

Definition 2.1 ([13])**.** A graph formed by connecting the central vertices of two star graphs $K\{1,m\}$ and $K\{1,n\}$ with a single edge is known as bi-star graph and is denoted by $B\{m,n\}$. Therefore, a bi-star graph $B\{m,n\}$ has a total of $(m+n+2)$ vertices and $(m+n+1)$ edges as shown in Figure 1.

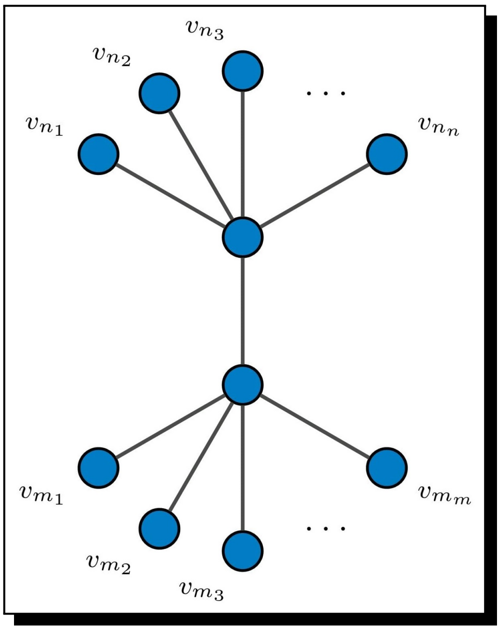

Figure 1. Bistar graph

Definition 2.2 ([8])**.** The ladder graph is formed by taking the cartesian product of a path with n-vertices (P_n) and a path with 2-vertices (P_2) that is $L_n = P_n \times P_2$ ($L_n = P_n \times K_2$), where P_n is a path with n-vertices and K_2 is the complete graph with two vertices as shown in Figure 2.

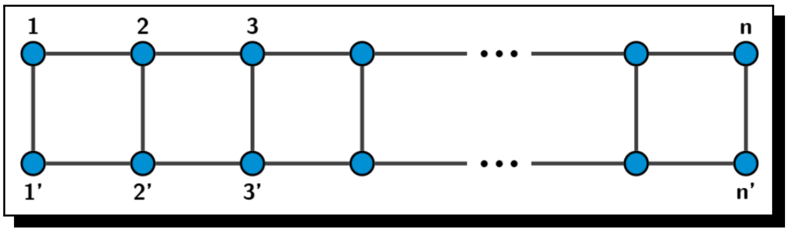

Figure 2. Ladder graph

Definition 2.3 ([8])**.** Let $L_n = P_n \times P_2$ ($n \geq 2$) be the ladder graph with vertex set u_i and v_i, $i = 1,2,3,\dots,n$. The alternate triangular belt graph is obtained from the ladder graph by adding the edges u_{2i+1}, v_{2i+2} for all $i = 0,1,2,3,\dots,n-1$ and v_{2i}, u_{2i+1} for all $i = 1,2,3,\dots,n-1$ as shown in Figure 3 and this graph is denoted by $ATB(n)$.

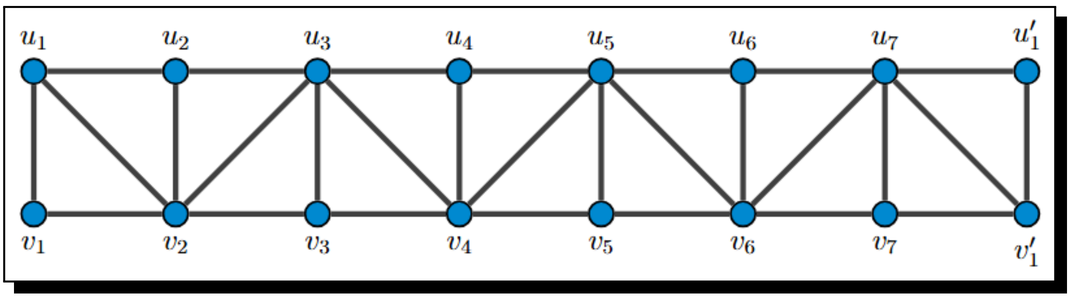

Figure 3. Alternate triangular belt graph

Definition 2.4 ([6])**.** An antiprism graph A_n is a polyhedral and planar graph that represents the skeleton of an antiprism. The number of vertices and edges in an n-antiprism graph is $2n$ and $4n$ respectively (shown in Figure 4) and it is isomorphic to the circulant graph (shown in Figure 5).

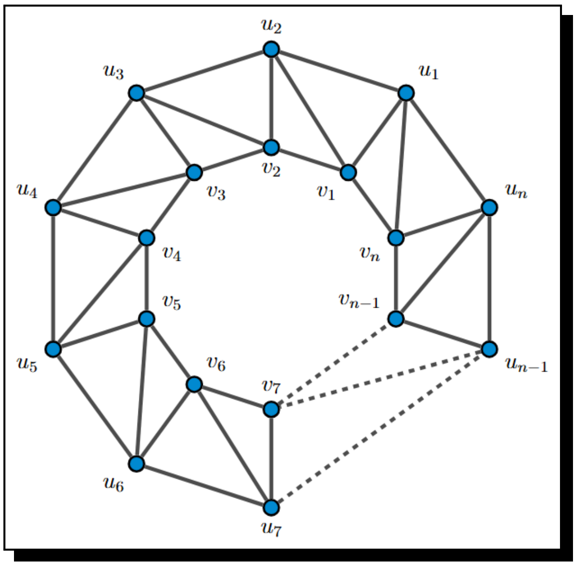

Figure 4. Antiprism graph

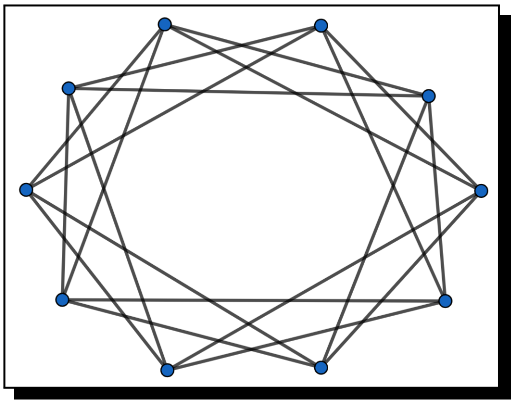

Figure 5. Circulant graph ($C_{10}^{2,3}$)

Definition 2.5 ([7])**.** The alternate pentagonal snake $A(PS_n)$ is constructed by transforming a path $p_1, p_2, \dots p_k$. This transformation involves adding two new vertices u_i and w_i between each pair of consecutive vertices p_i and p_{i+1}. Additionally, a new vertex x_i is connected to the vertices u_i and w_i. In this way, every alternate edge of the original path is replaced by a circle C_5 as shown in Figure 6.

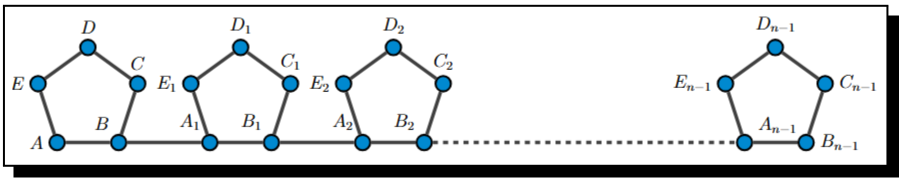

Figure 6. Alternate pentagonal snake $A(PS_n)$ graph

3. Main Results

Theorem 3.1. *Let a bi-star graph be G then the EG-domination number of G is*

$$\gamma_{ge}(G) = m + n.$$

Proof. In this context, the bi-star graph $G = B\{m,n\}$ contains two central vertices p and q such that m pendant vertices are adjacent to p and n pendant vertices are adjacent to q which is a total of $m+n+2$ vertices and $m+n+1$ edges. Now, to identify the edge geodetic dominating set, if we consider the set $\{p,q\}$ then we observe that this set is dominating but not an EG-set.

Thus, to make the set EG, all the edge must be included in a geodesic connecting any two of the vertices of the set. Therefore, we have to take all the pendant vertices of the bi-star graph so that all the edges can be included in the geodesic. So, we identified the set $\{v_{n_1}, v_{n_2}, \ldots, v_{n_n}, v_{m_1}, v_{m_1}, \ldots, v_{m_m}\}$ as the EG-set and also a dominant set containing the minimal number of vertices of the bi-star graph forming the edge geodetic dominant set. Hence

$$\gamma_{ge}(G) = m + n.$$ □

Theorem 3.2. *For $n \geq 2$, the EG-domination number of the ladder graph L_n is n i.e.,*

$$\gamma_{ge}(L_n) = n.$$

Proof. We know that the ladder graph $L_n = P_n \times K_2$ consists of two paths $u_1, u_2, \ldots, u_n$ and $v_1, v_2, \ldots, v_n$ and $2(n-1)$ horizontal edges and n vertical rungs so, $3n-2$ total edges.

Thus, we choose the vertices of the graph so that all the edges of the graph are in the geodetic joining any two of the vertices and the set formed is also a dominating set. Accordingly, we identified the set $\{u_1, v_2, u_3, v_4, \ldots, u_{n-1}, v_n\}$ which satisfies the conditions of the edge geodetic dominating set and contains minimal number of vertices. Hence,

$$\gamma_{ge}(L_n) = n.$$ □

Theorem 3.3. *Let J_n be the jewel graph where n is the vertex count adjacent to u and v both and these n vertices are not adjacent to each other furnish the edge geodetic domination number i.e.,*

$$\gamma_{ge}(J_n) = 4.$$

Proof. Here $G = J_n$ is a jewel graph with n vertices in such a way

$$V(G) = \{x, y, u, v, v_i | 1 \leq i \leq n\}$$

and

$$E(G) = \{xy, ux, vx, uy, vy, uv_i, vv_i | 1 \leq i \leq n\}.$$

In this context, $V(G) = n+4 = p$, $E(G) = 2n+5 = q$.

For Figure 7, we observe that a set containing the vertices u and v i.e., $\{u,v\}$ is the dominating set but not the edge geodetic set because the geodesic joining u and v does not contain all the edges of the graph. So, we identified the set $\{u,v,x,y\}$, which is together an edge geodetic and a dominant set. Hence,

$$\gamma_{ge}(J_n) = 4.$$ □

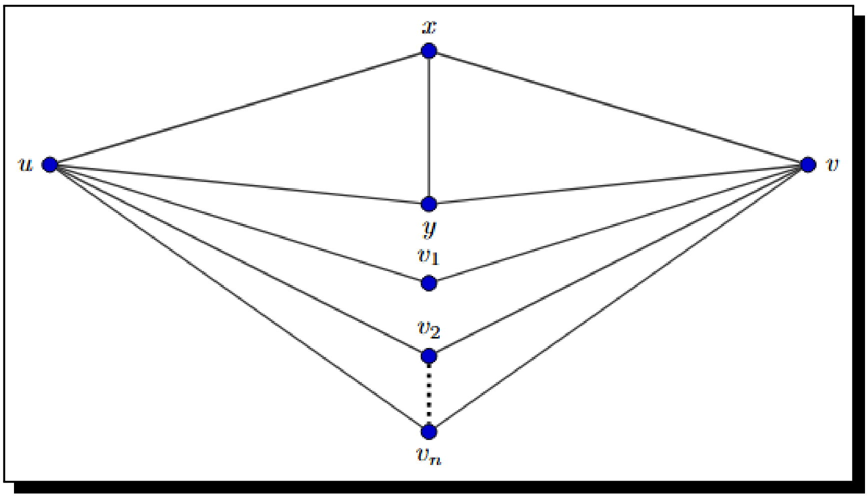

Figure 7. J_n

Theorem 3.4. *Let $G = H_n$ be the Helm graph then the EG-domination number of G is given by*

$$\gamma_{ge}(G) = n + 1.$$

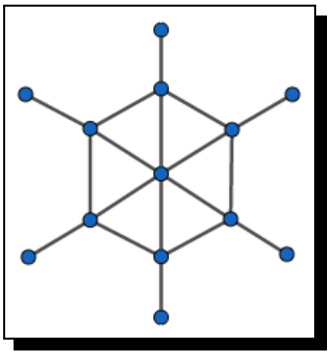

Figure 8. H_6

Proof. Let $\{v_1, v_2, v_3, \dots, v_n, v_{n+1}, v_{n+2}, \dots, v_{2n}, v_{2n+1}\}$ be the set of all the vertices of the Helm graph, where $v_1, v_2, \dots, v_n$ are the vertices on the cycle of the Helm graph and $v_{n+1}, v_{n+2}, \dots, v_{2n}$ are the pendant vertices adjacent to the vertices on the cycle and v_{2n+1} is the central vertex (Figure 8).

We observe that the set of vertices on the cycle of the Helm graph i.e., $\{v_1, v_2, v_3, \dots, v_n\}$ is the dominating set but not the EG-set so to cover all the edges in the geodetic we identified the set having all the pendant vertices and the central vertex i.e., $\{v_{n+1}, v_{n+2}, \dots, v_{2n}, v_{2n+1}\}$ forms the EG-dominating set and we observe that it is also the minimal EG-dominating set. Hence

$$\gamma_{ge}(G) = n + 1.$$ □

Theorem 3.5. *For any antiprism graph A_n, $n \geq 5$, the EG-dominant number always exists.*

Proof. Let G be an antiprism graph A_n with $2n$-vertices and $4n$-edges.

To prove this theorem, we make a table providing the edge geodetic domination number for different values of n.

S. No.	Value of n	Edge geodetic domination number of P_n
1	$n=5$	$\gamma_{ge}(A_n)=4$
2	$n=6$	$\gamma_{ge}(A_n)=5$
3	$n=7$	$\gamma_{ge}(A_n)=5$
4	$n=8$	$\gamma_{ge}(A_n)=6$
5	$n=9$	$\gamma_{ge}(A_n)=6$
6	$n=10$	$\gamma_{ge}(A_n)=6$
7	$n=11$	$\gamma_{ge}(A_n)=7$
8	$n=12$	$\gamma_{ge}(A_n)=7$
9	$n=13$	$\gamma_{ge}(A_n)=8$
10	$n=14$	$\gamma_{ge}(A_n)=8$
11	$n=15$	$\gamma_{ge}(A_n)=8$
12	$n=16$	$\gamma_{ge}(A_n)=9$
13	$n=17$	$\gamma_{ge}(A_n)=9$
14	$n=18$	$\gamma_{ge}(A_n)=10$
15	$n=19$	$\gamma_{ge}(A_n)=10$
16	$n=20$	$\gamma_{ge}(A_n)=10$

By analyzing the table, we conclude that this table follows different conditions and based on these conditions we derive the formulae for $\gamma_{ge}(G)$ which are as follows:

Condition 1: If $n \equiv 0 \pmod 5$ then $\gamma_{ge}(G) = 0.4n + 2$.

Condition 2: If $n \equiv 1 \pmod 5$ then $\gamma_{ge}(G) = 0.4n + 2.6$.

Condition 3: If $n \equiv 2 \pmod 5$ then $\gamma_{ge}(G) = 0.4n + 2.2$.

Condition 4: If $n \equiv 3 \pmod 5$ then $\gamma_{ge}(G) = 0.4n + 2.8$.

Condition 5: If $n \equiv 4 \pmod 5$ then $\gamma_{ge}(G) = 0.4n + 2.4$. □

Theorem 3.6. *For any $A(PS_n)$ graph, the EG-dominant number exists for all $n \geq 3$.*

Proof. We know that an $A(PS_n)$ graph has $5n$-vertices and $5n + (n-1)$ edges.

To prove this theorem, we make a table providing the edge geodetic domination number for different values of n.

S. No.	Value of n	Edge geodetic domination number of P_n
1	$n=3$	$\gamma_{ge}(A(PS_n))=7$
2	$n=4$	$\gamma_{ge}(A(PS_n))=8$
3	$n=5$	$\gamma_{ge}(A(PS_n))=10$
4	$n=6$	$\gamma_{ge}(A(PS_n))=12$
5	$n=7$	$\gamma_{ge}(A(PS_n))=13$
6	$n=8$	$\gamma_{ge}(A(PS_n))=15$
7	$n=9$	$\gamma_{ge}(A(PS_n))=17$
8	$n=10$	$\gamma_{ge}(A(PS_n))=18$

(Table *continued*)

S. No.	Value of n	Edge geodetic domination number of P_n
9	$n = 11$	$\gamma_{ge}(A(PS_n)) = 20$
10	$n = 12$	$\gamma_{ge}(A(PS_n)) = 22$
11	$n = 13$	$\gamma_{ge}(A(PS_n)) = 23$
12	$n = 14$	$\gamma_{ge}(A(PS_n)) = 25$
13	$n = 15$	$\gamma_{ge}(A(PS_n)) = 27$
14	$n = 16$	$\gamma_{ge}(A(PS_n)) = 28$
15	$n = 17$	$\gamma_{ge}(A(PS_n)) = 30$
16	$n = 18$	$\gamma_{ge}(A(PS_n)) = 32$

By analyzing the table, we conclude that this table follows different conditions and based on these conditions we derive the formulae for $\gamma_{ge}(G)$ which are as follows:

Condition 1: If $n \equiv 0 \pmod 3$ then we diagnosed $\gamma_{ge}(G) = \frac{5n}{3} + 2$.

Condition 2: If $n \equiv 1 \pmod 3$ then we diagnosed $\gamma_{ge}(G) = \frac{5n}{3} + \frac{4}{3}$.

Condition 3: If $n \equiv 2 \pmod 3$ then we diagnosed $\gamma_{ge}(G) = \frac{5n}{3} + \frac{5}{3}$. □

Theorem 3.7. *For any graph G*

$$\left\lceil \frac{n}{1+\Delta(G)} \right\rceil \le \gamma_{ge}(G) \le n - \Delta(G) + 1$$

where $\lceil \cdot \rceil$ *represents the ceiling function.*

Proof. Let G be a graph and D be the dominating set of G. Each edge of G is contained in a geodesic joining a vertex and the vertex having maximum cardinality or any other vertex and every vertex can be dominated by at most itself and the remaining vertices by the vertex with $\Delta(G)$, so lower bound for $\gamma_{ge}(G)$ is $\left\lceil \frac{n}{1+\Delta(G)} \right\rceil$ i.e.,

$$\gamma_{ge}(G) \ge \left\lceil \frac{n}{1+\Delta(G)} \right\rceil .$$

For the upper bound, let v represents a highest degree vertex $\Delta(G)$. Then $N[v]$ dominated by v be a vertex of maximum degree and there must be at least one vertex 'a' from $N[v]$ or other than $N[v]$ in such a manner that a geodesic joining 'a' with either v or $N[v]$ contains each edge of G. Hence, $V - N(v) \cup \{a\}$ is an EG-dominating set of cardinal number $n - \Delta(G) + 1$. Hence,

$$\left\lceil \frac{n}{1+\Delta(G)} \right\rceil \le \gamma_{ge}(G) \le n - \Delta(G) + 1 .$$ □

Theorem 3.8. *Let G be a connected graph with* $\delta(G) \ge 2$ *and* $G \notin A$*, then* $\gamma_{ge}(G) \le \frac{2n}{5}$ *(where A represents graphs in family A as shown in Figure* 9*).*

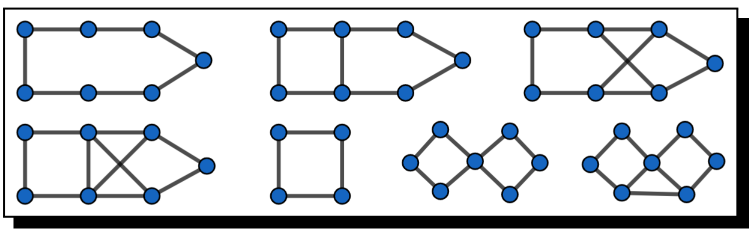

Figure 9. Graphs in family A

Theorem 3.9. *Let G be a connected graph with $\delta(G) \geq 2$ and $\gamma_{ge}(G) = \lfloor \frac{n}{2} \rfloor$, then $G \in A \cup B$, where $\lfloor \cdot \rfloor$ represents the floor function (where A and B represents graphs in families A and B shown in Figures 9 and 10).*

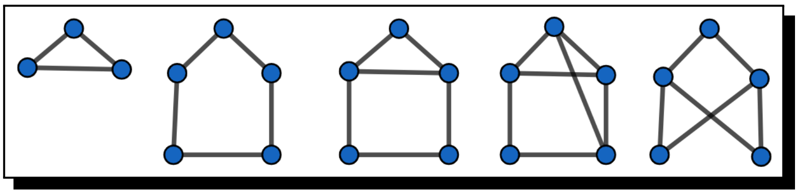

Figure 10. Graphs in family B

Proof. Let G be a connected graph such that $\delta(G) \geq 2$ and $\gamma_{ge}(G) = \lfloor \frac{n}{2} \rfloor$.
From Theorem 3.8, if $G \notin A$ then $\gamma_{ge}(G) \leq \frac{2n}{5}$.

Now two cases arises:

Case 1. If n is even.
Here n is an even number which implies that

$$\gamma_{ge}(G) = \left\lfloor \frac{n}{2} \right\rfloor \leq \frac{2n}{5},$$

which is a contradiction.

Case 2. If n is odd.
So, $\gamma_{ge}(G) = \lfloor \frac{n}{2} \rfloor \leq \frac{2n}{5}$ implies only that $n = 3$ or $n = 5$ means that all graphs of order three or five follows this condition and $\delta(G) \geq 2$ and $\gamma_{ge}(G) = \lfloor \frac{n}{2} \rfloor$ are in B.
Hence from both the cases we conclude that $G \in A \cup B$. □

Theorem 3.10. *Let $G = P_n$ $(n \geq 2)$ be a path graph then the edge geodetic dominant number of the path graph with linear structure in which successive vertex is adjacent to only preceding vertex, i.e., a line graph (as shown in Figure 11) has*

$$\gamma_{ge}(P_n) = \begin{cases} 5, & \text{if } n = 2,3,4, \\ \lfloor \frac{n-5}{3} \rfloor + 3, & \text{otherwise.} \end{cases}$$

where $\lfloor \cdot \rfloor$ represents the floor function.

Proof. We prove this theorem by finding the edge geodetic domination number of some graphs and then by generalizing the result. Therefore, we make a table for edge geodetic domination number for different values of n of the path graph P_n.

Hence, by the generalization from the values of the above table we have

$$\gamma_{ge}(P_n) = \left\lfloor \frac{n-5}{3} \right\rfloor + 3, \quad n \geq 5.$$

□

Figure 11. Path graph (P_n)

S. No.	Value of n	Edge geodetic domination number of P_n
1	$n=2$	$\gamma_{ge}(P_2)=2$
2	$n=3$	$\gamma_{ge}(P_3)=2$
3	$n=4$	$\gamma_{ge}(P_4)=2$
4	$n=5$	$\gamma_{ge}(P_5)=3$
5	$n=6$	$\gamma_{ge}(P_6)=3$
6	$n=7$	$\gamma_{ge}(P_7)=3$
7	$n=8$	$\gamma_{ge}(P_8)=4$
8	$n=9$	$\gamma_{ge}(P_9)=4$
9	$n=10$	$\gamma_{ge}(P_{10})=4$
10	$n=11$	$\gamma_{ge}(P_{11})=5$
11	$n=12$	$\gamma_{ge}(P_{12})=5$
12	$n=13$	$\gamma_{ge}(P_{13})=5$
13	$n=14$	$\gamma_{ge}(P_{14})=6$
14	$n=15$	$\gamma_{ge}(P_{15})=6$
15	$n=16$	$\gamma_{ge}(P_{16})=6$
16	$n=17$	$\gamma_{ge}(P_{17})=7$

Definition 3.1 ([3]). A graph G on vertices $V=\{v_1,v_2,\dots,v_n\}$ is said to be Mycielski graph $\mu(G)$ of G if

$$V(\mu(G))=\{X\cup Y\cup\{z\}\}=\{v_1,v_2,\dots,v_n,u_1,u_2,\dots,u_n,v\},$$

where v is adjacent to every u_i and if $v_iv_j\in E(G)$, then $v_iu_j,u_iv_j\in E(\mu(G))$. In other words, the Mycielski graph of a path graph P_n is created by taking a copy of the path graph, duplicating each vertex and adding a new vertex connected to all the duplicated vertices as shown in Figure 12.

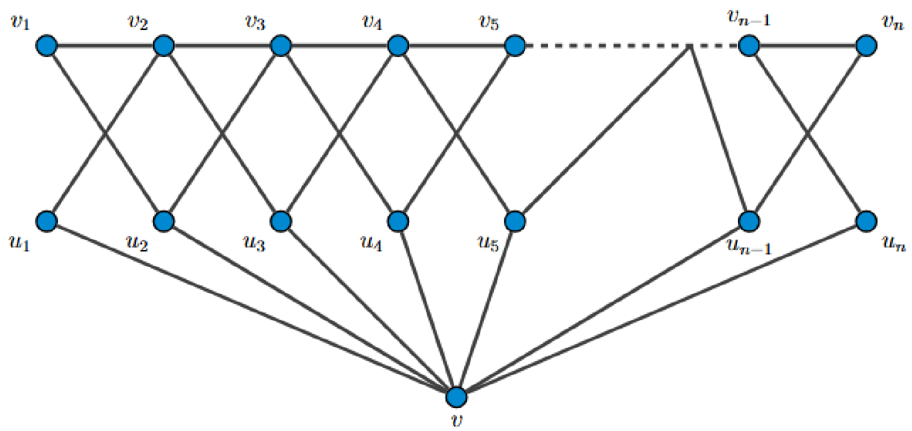

Figure 12. Mycielski graph

Theorem 3.11. *Let G be the Mycielski graph then the EG-domination number of G is given by*

$$\gamma_{ge}(\mu(G))=\left\lfloor\frac{n-5}{3}\right\rfloor+6,\quad n\ge 5,$$

where $\lfloor\cdot\rfloor$ represents the floor function.

4. Conclusion

In this paper, we identified the edge geodetic dominant number of different graphs like bistar graph, jewel graph, ladder graph, Helm graph, antiprism graph A_n, alternate triangular snake $A(PS_n)$ graph, path graph, Mycielski graph and the upper and lower bound of the edge geodetic domination number. We also observed that with the help of edge geodetic dominating set we can visit each and every part of the graph and hence the edge geodetic domination is a rapidly developing field of graph theory because in this complete graph can be analyzed significantly. So, to advance this field, future research should focus on the EG-dominant set of generalized graphs.

5. Future Work

(1) Determine the edge geodetic domination number for additional classes of graphs such as trees, bipartite graphs, planar graphs and chordal graphs.

(2) Investigate the computational complexity of the edge geodetic domination number and develop efficient algorithms for special graph classes.

(3) Analyze the behavior of the edge geodetic domination number under graph operations and graph products.

(4) Examine relationships between the edge geodetic domination number and other domination numbers.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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