



On Connected Eccentric Domination in Graphs

M.Bhanumathi

Government Arts College for Women, Pudukkottai-622001, Tamilnadu, India.

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ABSTRACT

A subset D of the vertex set $V(G)$ of a graph G is said to be a dominating set if every vertex not in D is adjacent to at least one vertex in D . A dominating set D is a connected dominating set, if $\langle D \rangle$ is a connected subgraph of G . For a Connected Graph G , a connected dominating set D is said to be a connected eccentric dominating set if for every $v \in V - D$, there exists at least one eccentric point of v in D . The minimum of the cardinalities of the connected eccentric dominating sets of G is called the connected eccentric domination number $\gamma_{ced}(G)$ of G . In this paper, bounds for γ_{ced} and its exact value for some particular classes of graphs are found.

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Introduction

Let G be a finite, simple, undirected connected graph on n vertices with vertex set $V(G)$ and edge set $E(G)$. For graph theoretic terminology refer to Harary [8], Buckley and Harary [6].

Definition. 1.1

Let G be a connected graph and v be a vertex of G . The eccentricity $e(v)$ of v is the distance to a vertex farthest from v . Thus, $e(v) = \max \{d(u, v) : u \in V\}$. The radius $r(G)$ is the minimum eccentricity of the vertices, whereas the diameter $\text{diam}(G)$ is the maximum eccentricity. For any connected graph G , $r(G) \leq \text{diam}(G) \leq 2r(G)$. v is a central vertex if $e(v) = r(G)$. The center $C(G)$ is the set of all central vertices. The central subgraph $\langle C(G) \rangle$ of a graph G is the subgraph induced by the center. v is a peripheral vertex if $e(v) = \text{diam}(G)$. The periphery $P(G)$ is the set of all peripheral vertices.

For a vertex v , each vertex at a distance $e(v)$ from v is an eccentric vertex. Eccentric set of a vertex v is defined as $E(v) = \{u \in V(G) : d(u, v) = e(v)\}$.

Definition. 1.2

The open neighborhood $N(u)$ of a vertex v is the set of all vertices adjacent to v in G . $N[v] = N(v) \cup \{v\}$ is called the closed neighborhood of v . For a vertex $v \in V(G)$, $N_i(u) = \{u \in V(G) : d(u, v) = i\}$ is defined to be the i^{th} neighborhood of v in G .

Definition 1.3 [7, 9, 11]

A set $S \subseteq V$ is said to be a dominating set in G , if every vertex in $V - S$ is adjacent to some vertex in S . A dominating set D is an independent dominating set, if no two vertices in D are adjacent that is D is an independent set. A dominating set D is a connected dominating set, if $\langle D \rangle$ is a connected subgraph of G . A set $D \subseteq V(G)$ is a global dominating set, if D is a dominating set of G and $\bar{G}$.

We have defined and studied eccentric domination and related concepts in [1], [2], [3], [4] and [10].

Definition. 1.4 [10]

A set $D \subseteq V(G)$ is an eccentric dominating set if D is a dominating set of G and for every $v \in V - D$, there exists at least one eccentric point of v in D . If D is an eccentric dominating set, then every superset $D' \supseteq D$ is also an eccentric dominating set. But $D'' \subsetneq D$ is not necessarily an eccentric dominating set. An eccentric dominating set D is a minimal eccentric dominating set if no proper subset $D'' \subsetneq D$ is an eccentric dominating set.

Definition. 1.5[10]

The eccentric domination number $\gamma_{ed}(G)$ of a graph G equals the minimum cardinality of an eccentric dominating set. That is, $\gamma_{ed}(G) = \min |D|$, where the minimum is taken over D in D , where D is the set of all minimal eccentric dominating sets of G .

Definition. 1.6[10]

Eccentric point set of G

Let $S \subseteq V(G)$. Then S is known as an eccentric point set of G if for every $v \in V - S$, S has at least one vertex u such that $u \in E(v)$.

An eccentric point set S of G is a minimal eccentric point set if no proper subset S' of S is an eccentric point set of G .

S is known as a minimum eccentric point set if S is an eccentric point set with minimum cardinality. Let $e(G)$ be the cardinality of a minimum eccentric point set of G . $e(G)$ can be called as eccentric number of G .

Tele:

E-mail addresses: bhanu_ksp@yahoo.com

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Definition. 1.7[5]

A set $S \subseteq V(G)$ is a total eccentric dominating set if S is an eccentric dominating set and also the induced sub graph $\langle S \rangle$ has no isolated vertices. The cardinality of minimum total eccentric dominating set is called the total eccentric domination number and is denoted by $\gamma_{te}(G)$. Clearly, For any graph G , $\gamma(G) \leq \gamma_t(G) \leq \gamma_{te}(G)$.

Theorem. 1.1[10]

- (i) $\gamma_{ed}(K_{1,n}) = 2$, $n \geq 2$.
- (ii) $\gamma_{ed}(K_{m,n}) = 2$.
- (iii) $\gamma_{ed}(W_3) = 1$, $\gamma_{ed}(W_4) = 2$, $\gamma_{ed}(W_n) = 3$, for $n = 5$, $\gamma_{ed}(W_6) = 2$, $\gamma_{ed}(W_n) = 3$ for $n \geq 7$.

Theorem. 1.2[9]

For any connected graph G , $\gamma_c(G) \leq n - \Delta(G)$.

Theorem. 1.3[9]

For any connected graph G , $\gamma_c(G) = n - \epsilon_T(G)$, where $\epsilon_T(G)$ is the maximum number of pendent edges in any spanning tree of G .

Theorem. 1.4[5]

$$\gamma_{te}(C_3) = 2.$$

$$\gamma_{te}(C_n) = \begin{cases} \frac{n}{2} & \text{if } n = 4m \\ \left\lceil \frac{n}{2} \right\rceil & \text{if } n = 4m + 1 \\ \frac{n}{2} + 1 & \text{if } n = 4m + 2 \\ \left\lceil \frac{n}{2} \right\rceil + 1 & \text{if } n = 4m + 3, \text{ where } m \text{ is odd} \end{cases}$$

$$\gamma_{te}(C_n) = \begin{cases} \frac{n}{2} + 2 & \text{if } n = 4m \\ \left\lceil \frac{n}{2} \right\rceil + 1 & \text{if } n = 4m + 1 \\ \frac{n}{2} + 1 & \text{if } n = 4m + 2 \\ \left\lceil \frac{n}{2} \right\rceil & \text{if } n = 4m + 3, \text{ where } m \text{ is even} \end{cases}$$

Connected Eccentric domination in Graphs

The various domination parameters introduced till now find many applications in covering of entire graph by the different sets with each of which has some specified property. These concepts are helpful to find centrally located sets to cover entire graph in which they are defined. The concept of eccentric set of a node has application in the location of farthest set of a node of a graph and hence in [1, 2, 3, 4, 10], Bhanumathi and Muthammai defined a new concept named eccentric domination and studied the structural properties of graphs using this concept.

In [3], Bhanumathi and Muthammai initiated the study of connected eccentric domination in graphs.

For a Connected Graph G , a connected dominating set D is said to be a connected eccentric dominating set if for every $v \in V - D$, there exists at least one eccentric point of v in D . The minimum of the cardinalities of the connected eccentric dominating sets of G is called the connected eccentric domination number $\gamma_{ced}(G)$ of G . Connected eccentric domination number is defined for connected graphs only. So, for the rest of this section, assume that G is a connected Graph. $V(G)$ is a connected eccentric dominating set for any connected graph G . Hence, $\gamma_{ced}(G)$ is a well defined parameter.

Obviously, $\gamma(G) \leq \gamma_{ed}(G) \leq \gamma_{ced}(G)$ and $\gamma_c(G) \leq \gamma_{ced}(G) \leq \gamma_c(G) + e(G)$.

Since any connected eccentric dominating set is also a total eccentric dominating set, we have, $\gamma_{ed}(G) \leq \gamma_{te}(G) \leq \gamma_{ced}(G)$. The sharpness of this inequality follows from $G = K_{m,n}$, $m, n \geq 2$, since $\gamma_{ed}(G) = \gamma_{te}(G) = \gamma_{ced}(G) = 2$. On the other hand, the inequality is also strict. For example, by theorem 1.3, $\gamma_{te}(C_n) = n/2$, when $n = 4m$ and m is odd, and $\gamma_{ced}(C_n) = n-2$ for all n , where $n \geq 4$.

Clearly, D is a minimal connected eccentric dominating set if and only if at least one of the following conditions hold good.

- (i) For every vertex $v \in D$, there exists $w \in V - D$ such that w is uniquely dominated by v .
- (ii) Every point $v \in D$ is unique eccentric point of some point $w \in V - D$ in D that is all other eccentric points of $w \in V - D$ lie in $V - D$ only.
- (iii) $v \in D$ is a cut point of $\langle D \rangle$.

The connected eccentric domination numbers of some standard classes of graphs are given in the following theorem.

Theorem. 2.1

- (i) $\gamma_{ced}(K_n) = 1$.
- (ii) $\gamma_{ced}(K_{1,n}) = 2$, $n \geq 2$.
- (iii) $\gamma_{ced}(K_{m,n}) = 2$.
- (iv) $\gamma_{ced}(W_3) = 1$, $\gamma_{ced}(W_4) = 2$, $\gamma_{ced}(W_n) = 3$, for $n = 5$, $\gamma_{ced}(W_6) = 2$, $\gamma_{ced}(W_n) = 3$ for $n \geq 7$.

Proof

Proof follows from the proof of Theorem 1.1.

Next, we discuss the bounds for $\gamma_{ced}(G)$

Since atleast one vertex and atmost $n - 1$ vertices are needed to dominate a connected graph G , we have $1 \leq \gamma_{ced}(G) \leq n-1$ for every graph G of order n . Both of these bounds are sharp, since $\gamma_{ced}(G) = 1$ if and only if $G = K_n$ and $\gamma_{ced}(G) = n-1$ if G is a path on n vertices. If $G \neq K_n$, we have $2 \leq \gamma_{ced}(G) \leq n-1$.

Theorem. 2.2

If d is the diameter of G , then $\gamma_{ced}(G) \geq d$.

Proof

Let G be a connected graph with diameter d . Let u and v be two peripheral vertices at distance d to each other. Let P be a diametral path joining u and v . Let D be a connected eccentric dominating set. If $u, v \in D$, then $|D| \geq d+1$. If any one of u, v is in D , then $|D| \geq d$. Hence, $\gamma_{ced}(G) \geq d$.

This lower bound is also sharp, since $\gamma_{ced}(G) = n-1$ if G is a path on n vertices.

Theorem. 2.3

For any connected graph G , $\gamma_{ced}(G) \leq n + e(G) - e_T(G)$, where $e_T(G)$ is the maximum number of pendent edges in any spanning tree of G .

Proof

By theorem 1.3, for any connected graph G , $\gamma_c(G) = n - e_T(G)$, where $e_T(G)$ is the maximum number of pendent edges in any spanning tree of G . Also, if D is a connected dominating set and S is a minimum eccentric point set of G , then $D \cup S$ is a connected eccentric dominating set of G . Therefore, $\gamma_{ced}(G) \leq \gamma_c(G) + e(G)$. Hence, the theorem follows.

Theorem. 2.4

For any connected graph G , $\gamma_{ced}(G) \leq n + e(G) - \Delta(G)$.

Proof

We have, $\gamma_c(G) \leq n - \Delta(G)$ by theorem 1.2. Hence the theorem follows from $\gamma_{ced}(G) \leq \gamma_c(G) + e(G)$.

Corollary. 2.4

For any tree T , $\gamma_{ced}(T) \leq n - \Delta(T) + 2$.

Proof

For any tree T , $e(T) = 2$. Hence, $\gamma_{ced}(T) \leq n - \Delta(T) + 2$.

Theorem. 2.5

$\gamma_{ced}(G) \leq \lfloor (n + \gamma_c(G)) / 2 \rfloor$.

Proof

If D is a γ_c -set of G , we can form a γ_{ced} -set S with $\gamma_c(G) + (n - \gamma_c(G)) / 2$ vertices. $\langle S \rangle$ is connected, since the vertices in $V - D$ are adjacent to vertices of D . Hence, $\gamma_{ced}(G) \leq \lfloor (n + \gamma_c(G)) / 2 \rfloor$.

This upper bound is sharp, since for $G = P_n$, $\gamma_{ced}(G) = n-1 = \lfloor (n + \gamma_c(G)) / 2 \rfloor$.

Theorem. 2.6

If G is of radius one and diameter two, then $\gamma_{ced}(G) \leq (n-t+2)/2$ where t is the number of vertices with eccentricity one.

Proof

Let $u \in V(G)$ such that $e(u) = 1$. Let t be the number of vertices with eccentricity one. u dominates all other vertices and for $t-1$ other vertices u is an eccentric point. Consider the remaining $(n-t)$ vertices of G . They are also dominated by u but their eccentric points are different from u and atmost $(n-t)/2$ vertices are needed to dominate them eccentrically. Since $e(u) = 1$, all other vertices are adjacent to u . Hence, $\gamma_{ced}(G) \leq 1 + (n-t)/2 = (n-t+2)/2$.

Theorem. 2.7

If G is of radius one and diameter two, then $\gamma_{ced}(G) \leq 2 + \lceil (\delta(G) - t) / 2 \rceil$, where t is the number of vertices with eccentricity one.

Proof

$V(G)$ can be partitioned into two sets V_1 and V_2 as follows. $V_1 = \{v \in V / e(v) = 1\}$ and $V_2 = \{v \in V / e(v) = 2\}$. Let u be a vertex in V_2 such that degree of u in $H = \langle V_2 \rangle$ is minimum. Let $\deg_H u = \delta_2 = \delta(G) - t$. Then u is eccentric to the remaining $n-t-\delta_2$ vertices. Let S be a subset of $N_H(u)$ such that vertices in $N_H(u) - S$ have their eccentric vertices in S . Hence, $\{u, v\} \cup S$, where $v \in V_1$ is a connected eccentric dominating set of G . Therefore, $\gamma_{ced}(G) \leq 2 + \lceil (\delta(G) - t) / 2 \rceil$.

This upper bound is also sharp, since for $G = K_{1,n-1}$, $\gamma_{ced}(G) = 2$.

Theorem. 2.8

If G is of diameter two, $\gamma_{ced}(G) \leq 1 + \delta(G)$.

Proof

$\text{diam}(G) = 2$. Let $u \in V(G)$ such that $\deg_G u = \delta(G)$. Consider, $D = \{u\} \cup N(u)$. This is a connected eccentric dominating set for G . Therefore, $\gamma_{ced}(G) \leq \delta(G) + 1$.

Corollary. 2.8

If G and $\bar{G}$ are self centered of diameter 2, then $\gamma_{ced}(G) + \gamma_{ced}(\bar{G}) \leq n + \delta - \Delta + 1$.

Proof

By Theorem 2.6, $\gamma_{ced}(G) \leq 1 + \delta$ and $\gamma_{ced}(\bar{G}) \leq 1 + \delta(\bar{G}) = 1 + \bar{\delta}$.

Hence $\gamma_{ced}(G) + \gamma_{ced}(\bar{G}) \leq 1 + \delta + 1 + \bar{\delta} = 2 + \delta + (n-1-\Delta) = n + \delta - \Delta + 1$.

Theorem. 2.9

If G is of radius two and diameter three and if G has a pendent vertex v of eccentricity 3 then $\gamma_{ced}(G) \leq 1 + \Delta(G)$.

Proof

If G has a pendent vertex v of eccentricity 3 then its support u is of eccentricity 2. In this case $N[u]$ is a connected eccentric dominating set. Thus, $\gamma_{ced}(G) \leq 1 + \deg_G u \leq 1 + \Delta(G)$.

Theorem. 2.10

If G is of radius two and diameter three, then $\gamma_{ced}(G) \leq \min \{(n + \deg_G u + 1)/2\}$, where the minimum is taken over all central vertices.

Proof

Let u be a central vertex with minimum degree. Consider $N(u)$. $N(u)$ dominates all the vertices of G and all the vertices in $N_2(u)$ are eccentric to u . Let S be a subset of $N_2(u)$ with minimum cardinality such that vertices in $N_2(u) - S$ has their eccentric vertices in S . Then $|S| \leq |N_2(u)|/2 = (n - \deg_G u - 1)/2$. Now $N[u] \cup S$ is a connected eccentric dominating set of G .

Hence, $\gamma_{ced}(G) \leq 1 + \deg_G u + (n - \deg_G u - 1)/2 = (n + \deg_G u + 1)/2$. This proves the theorem.

Following theorems deal with connected eccentric domination number of trees.

Theorem. 2.11

For a tree T , $\gamma_{ced}(T) \leq n - p + 2$, where p is the number of pendent vertices of T .

Proof

Let D be the set of all pendent vertices of T . Let u, v be any two pendent vertices such that $d(u, v) = \text{diam}(T)$. Then $(V(T) - D) \cup \{u, v\}$ is a connected eccentric dominating set of T . Hence, $\gamma_{ced}(T) \leq n - p + 2$.

Theorem. 2.12

For a tree T , $\gamma_{ced}(T) = n - p + 1$ or $n - p + 2$, where p is the number of pendent vertices of T .

Proof

We know that, $\gamma_c(T) \leq \gamma_{ced}(T)$ and $\gamma_c(T) = n - p$. Also, there exists no minimum connected dominating set of T , which is an eccentric dominating set for T . Hence, $\gamma_c(T) < \gamma_{ced}(T)$. Hence, $n - p < \gamma_{ced}(G) \leq n - p + 2$. This proves the theorem.

Theorem. 2.13

For a tree T , $\gamma_{ced}(T) = n - p + 1$ if and only if there exists a peripheral vertex which is an eccentric vertex of every other pendent vertices, otherwise $\gamma_{ced}(T) = n - p + 2$, where p is the number of pendent vertices of T .

Proof

Let D be the set of all pendent vertices of T . Let u be a peripheral vertex which is an eccentric vertex of every other pendent vertex. Then $(V(T) - D) \cup \{u\}$ is a minimum connected eccentric dominating set of T and $\gamma_{ced}(T) = n - p + 1$. On the other hand, suppose $\gamma_{ced}(T) = n - p + 1$. Since $\gamma_c(T) = n - p$ and $V(T) - D$ is the only minimum connected dominating set, $\gamma_{ced}(T) = n - p + 1$ implies that $S = (V(T) - D) \cup \{x\}$, where x is a pendent vertex is a connected eccentric dominating set. But S is a γ_{ced} -set implies that x is the eccentric vertex of all other pendent vertices. This proves the Theorem.

Corollary. 2.13

$\gamma_{ced}(P_n) = n - 1$ for all n .

Now, let us find the connected eccentric domination number of cycles and their complements.

Theorem. 2.14

$\gamma_{ced}(C_n) = n - 2$ for all n .

Proof

Let u, v be any two adjacent vertices of C_n . Then $V - \{u, v\}$ is a minimum connected eccentric dominating set of C_n . Hence, $\gamma_{ced}(C_n) \geq n - 2$ for all n . Also, $\gamma_c(C_n) \leq \gamma_{ced}(C_n)$ and $\gamma_c(C_n) = n - 2$. Therefore, $\gamma_{ced}(C_n) = n - 2$ for all n .

Theorem. 2.15

$\gamma_{ced}(\overline{C}_5) = 3$ and $\gamma_{ced}(\overline{C}_n) = \lceil n/3 \rceil$, $n \geq 6$.

Proof

We have $\gamma_{ced}(\overline{C}_5) = 3$ and $\gamma_{ced}(\overline{C}_n) = \lceil n/3 \rceil$, $n \geq 6$. Also, $\gamma_{ced}(G) \leq \gamma_{ced}(G)$. Hence, $\gamma_{ced}(\overline{C}_n) \geq \lceil n/3 \rceil$. Clearly, $\gamma_{ced}(\overline{C}_5) = 3$. Now, assume that $n \geq 6$. Let $v_1, v_2, v_3, \dots, v_n, v_1$ form C_n . Then $\overline{C}_n = K_n - C_n$ and each vertex v_i is adjacent to all other vertices except v_{i-1} , and v_{i+1} in $\overline{C}_n$. Hence eccentric point of v_i in $\overline{C}_n$ is v_{i-1} , and v_{i+1} only. Now, we can consider a connected eccentric (minimal) dominating set as follows.

$\{v_1, v_4, v_7, \dots, v_{3m-2}\}$ if $n = 3m$;

$\{v_1, v_4, v_7, \dots, v_{3m+1}\}$ if $n = 3m+1$;

$\{v_1, v_4, v_7, \dots, v_{3m+1}, v_{3m+2}\}$ if $n = 3m+2$;

Hence $\gamma_{ced}(\overline{C}_n) \leq \lceil n/3 \rceil$. Thus, it follows that $\gamma_{ced}(\overline{C}_n) = \lceil n/3 \rceil$, for $n \geq 6$.

Following theorems give the exact value of connected eccentric domination number of $G \cdot K_1$ and $K_n - M$, where M is a perfect matching of K_n .

Theorem. 2.16

Let n be an even integer. Let G be obtained from the complete graph K_n by deleting edges of a linear factor. Then $\gamma_{ced}(G) = n/2$.

Proof

Consider $D \subseteq V(G)$ such that $\langle D \rangle = K_{n/2}$. D contains $n/2$ vertices such that each vertex in $V - D$ is adjacent to at least one element in D and each element in $V - D$ has its eccentric point in D and D is connected. Hence $\gamma_{ced}(G) \leq n/2$. Also, since G is unique eccentric point graph, we have $n/2 \leq \gamma_{ced}(G) \leq \gamma_{ced}(G)$. Hence, $\gamma_{ced}(G) = n/2$.

Theorem. 2.17

Let G be a connected graph with $|V(G)| = n$. Then $\gamma_{ced}(G \circ K_1) \leq 3n/2$.

Proof

Let $V(G) = \{v_1, v_2, \dots, v_n\}$. Let v_i' be the pendent vertex adjacent to v_i in $G \circ K_1$ for $i = 1, 2, \dots, n$. $D = \{v_1, v_2, \dots, v_n\}$ is a connected dominating set for $G \circ K_1$. Let S be a minimum eccentric point set of G . Let S' be the corresponding subset of $\{v_1', v_2', \dots, v_n'\}$. Then $S' \cup D$ is an eccentric dominating set for $G \circ K_1$ and $|S' \cup D| \leq 3n/2$.

Next theorem characterizes graphs for which $\gamma_{ced}(G) = 2$.

Theorem. 2.18

Let G be a connected graph. Then $\gamma_{ced}(G) = 2$ if and only if G is any one of the following:

- (i) $r(G) = 1$, $\text{diam}(G) = 2$ and $u \in V(G)$ such that $e(u) = 2$ and $d(u, v) = 2$ for all $v \in V(G)$ with $e(v) = 2$.
- (ii) G is self-centered of diameter 2, having a dominating edge which is not in a triangle.

Proof

When G satisfies any one of the above conditions obviously $\gamma_{ced}(G) = 2$.

On the other hand, assume that $\gamma_{ced}(G) = 2$. Therefore, $\gamma(G) = 1$ or $\gamma(G) = 2$.

Case(i)

$\gamma(G) = 1$ and $\gamma_{ced}(G) = 2$. This implies G satisfies (i).

Case(ii)

$$\gamma(G) = 2 = \gamma_{ced}(G)$$

Let D be a minimum γ_{ced} -dominating set of G . Let $D = \{u, v\} \subseteq V(G)$. Since $\gamma(G) = 2$, $r(G) \geq 2$.

Since D is connected u and v are adjacent and the edge uv is a dominating edge for G . Therefore, $r(G) \geq 2$ and $2 \leq \text{diam}(G) \leq 3$. Suppose $\text{diam}(G) = 3$, there exists a vertex x with eccentricity 3 and x is dominated by u or v .

Let $xu \in E(G)$. Now, D is an γ_{ced} -set. Hence v must be an eccentric point of x . This implies that $d(x, v) = 3$. But xuv is a path $\Rightarrow d(x, v) = 2$, which is a contradiction. Hence, x must be a vertex with eccentricity 2. This implies that $\text{diam}(G) = 2$, that is G is self-centered with diameter 2. [There exists no w , adjacent to both u and v , since in that case, w has no eccentric point in D , since $r(G) \geq 2$]

Theorem. 2.19

$\gamma(G) = \gamma_{ced}(G) = 2$ if and only if there exists $e = uv \in E(G)$ such that every other vertices of G is adjacent to exactly one of u and v and G is 2-self-centered.

Proof

Follows from the previous theorem.

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