Domination number of complete restrained fuzzy graphs

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Abstract: This work is concerned with the restrained complete domination number and triple connected domination number of fuzzy graphs. Some basic definitions and needful results are given with an example. The necessary and sufficient conditions for the fuzzy graph to be a complete restrained domination set is formulated and proved. Also the relation between complete restrained domination set and n-dominated set is illustrated. Finally, triple connected domination number of a restrained complete fuzzy graph is provided.

Keywords: fuzzy graphs; complete restrained domination set; complete restrained domination number; triple connected domination number.

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1 Introduction

In order to measure the lack of certainty, further development to fuzzy sets was introduced by Zadeh (1965) and are motivated to handle fixing the membership degree of an element from some possible values. Therefore researchers have taken up the study and application of fuzzy graphs that have been extended from different perspectives such as, both quantitative and qualitative. The concept of domination in graphs evolved from a chess board problem known as the queen problem to find the minimum number of queens needed on an 8 × 8 chess board such that each square is either occupied or attacked by a queen. One possible application of the concept of restrained domination is that of prisoners and guards. Here, each vertex not in the restrained dominating set corresponds to a position of a prisoner, and every vertex in the restrained dominating set corresponds to a position of a guard. Note that each prisoner's position is observed by a guard's position (to effect security) while each prisoner's position is seen by at least one other prisoner's position (to protect the rights of prisoner's). To be cost effective, it is desirable to place as few guards as possible. The domination of graph theory was given in Allan and Laskar (1978), Hanes et al. (1998), Bondy and Murthy (1976), Cokayne and Hedetniee (1977) and Nagoorgani and Chandrasekarn (2006). Restrained domination in graphs is studied in Domke et al. (1999). Total restrained domination numbers of trees are discussed in Joanna and Cyman (2008). In Tuan and Canoy (2014) an independent restrained domination in graphs are studied. The concept of triple connected graphs with real life application was introduced in Sarala and Kavitha (2015) and Paulraj et al. (2012), considering the existence of a path containing any three vertices of a graph. The domination in fuzzy graph was explained in Nagoorgani and Chandrasekarn (2006), Nagoorgani and Hussain (2007) and Somasundram and Somasundram (1998) and strong arcs in fuzzy graph was given in Bhutani and Rosenfeld (2003) and Sahoo and Pal (2015b) discussed the concept of intuitionistic fuzzy competition graph. They also discuss intuitionistic fuzzy tolerance graph with application (Sahoo and Pal, 2016b), different types of products on intuitionistic fuzzy graphs (Sahoo and Pal, 2015a), modular and homomorphic product of intuitionistic fuzzy graphs and their degree (Sahoo and Pal, 2017b), intuitionistic fuzzy labeling graphs (Sahoo and Pal, 2016a), certain types of edge irregular intuitionistic fuzzy graphs (Sahoo and Pal, 2017a) and product of intuitionistic fuzzy graphs and degree (Sahoo and Pal, 2016c). Sahoo et al. (2017) introduced covering and paired domination in intuitionistic fuzzy graphs. Fuzzy graph is used in telecommunication system (Samanta and Pal, 2013). A new concept of fuzzy colouring of fuzzy graph is given in Samanta et al. (2015).

In this paper, we generalised the concept of the complete restrained domination and triple connected domination number in fuzzy graphs which is an untreated topic. In the sequel, we give some basic definitions and results are given. The necessary and sufficient condition for the fuzzy graph to be complete restrained domination set is formulated and proved. Also the relation between complete restrained domination set and n-dominated set is provided. Finally, triple connected domination number of a restrained complete fuzzy graph is studied.

2 Preliminaries

A graph is an ordered pair $G = (V, E)$, where V is the set of all vertices of G, which is non empty and E is the set of all edges of G. Two vertices x, y in a graph G are said to be adjacent in G if (x, y) is an edge of G. A simple graph is a graph without loops and multiple edges. A complete graph is a simple graph in which every pair of distinct vertices is connected by an edge. The complete graph on n vertices has $\frac{n(n-1)}{2}$ 2 edges.

First, we defined fuzzy set and fuzzy relation as follows.

Definition 2.1: A fuzzy subset μ on a set X is a map μ: X → [0, 1]. Let X and Y be two sets and let μ and v be fuzzy subsets of X and Y respectively. Then a fuzzy relation ρ from the fuzzy subset μ into the fuzzy subset v is a fuzzy subset ρ of $X \times Y$ such that ρ: $X \times X$ such that $\rho(x, y) \leq \min\{\mu(x), \mu(y)\}$ for all $x \in X$ and $y \in Y$. When $Y = X$ and μ is a fuzzy subset of X, a map ρ: $X \times X \rightarrow [0, 1]$ is called a fuzzy relation of μ if $\mu(x, y) \leq \min\{\mu(x), \mu(y)\}$ for all $x, y \in X$. Fuzzy relation ρ is called symmetric if $\rho(x, y) = \rho(y, x)$.

Now, we defined fuzzy graph, fuzzy path and fuzzy cycle as follows.

Definition 2.2: A fuzzy graph is a pair $G = (\sigma, \mu)$, where σ is a fuzzy subset of a set V and μ is a fuzzy relation on σ. It is assumed that V is defined and non empty, and μ is reflexive and symmetric. Thus, if $G = (\sigma, \mu)$ is a fuzzy graph, then σ: $V \rightarrow [0, 1]$, and μ: $V \times V \rightarrow [0, 1]$ is such that $\mu(u, v) \leq \sigma(u) \wedge \sigma(v)$ for all $u, v \in V$, where ^ denotes the minimum.

Definition 2.3: In a fuzzy graph $G = (\sigma, \mu)$, a path P of length n is a sequence of distinct nodes $u_0, u_1, \ldots, u_n$ such that $\mu(u_{i-1}, \underline{u_i}) > 0$, $i = 1, 2, \ldots, n$ and the degree of membership of a weakest arc is defined as its strength. If $u_0 = u_n$ and $n \geq 3$, then P is called a fuzzy cycle if it contains more than one weakest arc. A single node is considered as a trivial path of length 0.

Here, we defined the degree of the vertex of the fuzzy graph.

Definition 2.4: Let $G = (\sigma, \mu)$ be a fuzzy graph. The degree of a vertex u in G is denoted by $d(u)$ and is defined as $d(u) = \Sigma\mu(u, v)$, for all $(u, v) \in E$.

Now, we defined the connectedness between two nodes in fuzzy graph.

Definition 2.5: The strength of connectedness between two nodes u, v in a fuzzy graph G is $\mu(u, v) = \sup \mu^k(u, v)$: $k = 1, 2, 3, \ldots$, where $\mu^k(u, v) = \sup\{\mu(u, u_1) \wedge \mu(u_1, u_2 \wedge \ldots\ldots, \mu(u_{k-1}, v)\}$.

Here, we defined strong arc and isolated vertex in fuzzy graph.

Definition 2.6: An arc(u, v) is said to be a strong arc or strong edge, if $\mu(u, v) > \mu^\infty(u, v)$ and the node v is said to be strong neighbour of u. If (u, v) is not strong arc then v is called isolated node or isolated vertex.

Definition 2.7: Let G be a fuzzy graph and u be a node in G then there exists a node v such that (u, v) is a strong arc then we say that u dominates v.

Now, we defined fuzzy dominating set in fuzzy graph as follows.

Definition 2.8: Let G be a fuzzy graph. A subset D of V is said to be fuzzy dominating set of G if for every $v \in V - D$, there exists $u \in D$ such that u dominates v.

Here, we defined minimal dominating set and domination number of fuzzy graph.

Definition 2.9: A fuzzy dominating set D of a fuzzy graph G is called minimal dominating set of G if for every node $v \in D$, $D - \{v\}$ is not a dominating set.

Definition 2.10: Minimum cardinality among all minimal dominating set in G is called fuzzy domination number of G and is denoted by $\gamma(G)$.

Definition 2.11: Maximum cardinality among all minimal dominating sets is called upper fuzzy dominating number of G and is denoted by $\Gamma(G)$. A dominating set D of a fuzzy graph G is a minimum dominating set if $|D| = \gamma(G)$.

We defined connected dominating set and connected domination number as follow.

Definition 2.12: A dominating set D of a fuzzy graph $G = (\sigma, \mu)$ is connected dominating set if the induced fuzzy subgraph $\langle D \rangle$ is connected. The minimum cardinality of a connected dominating set of G is called the connected domination number of G and is denoted by $\gamma_c(G)$.

Definition 2.13: A set $S \subseteq V$ is a restrained complete dominating set of G if every vertex in $v \in S$, $N_G(S) = V - S$ is complete dominating set and $V - S$ has no isolated vertices. The minimum cardinality of a restrained complete dominating set is the restrained complete domination number of G denoted by $\gamma_{rn}(G)$.

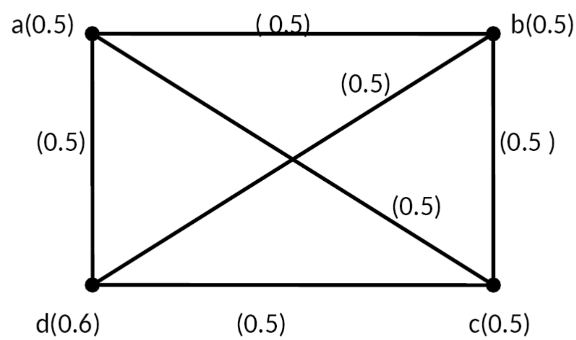
3 Main result

3.1 Restrained complete domination number

In this section, we defined regular and irregular fuzzy graph, totally regular and totally irregular fuzzy graph and restrained dominating set of a fuzzy graph.

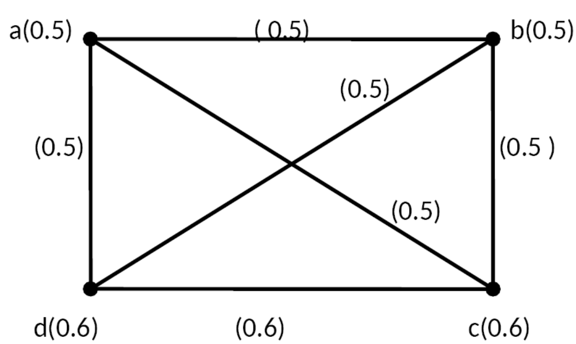
Definition 3.1: Let G be a complete fuzzy graph. A complete fuzzy graph G is said to be regular if each vertex has a same degree in G.

Figure 1 Fuzzy graph



Definition 3.2: Let G be a complete fuzzy graph. A complete fuzzy graph G is said to be irregular if each vertex has a distinct degree.

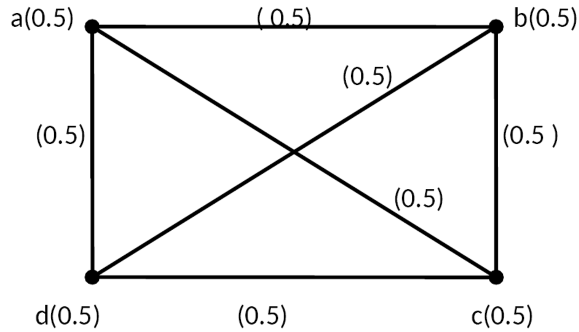
Figure 2 Complete fuzzy graph



Now, we defined totally regular and totally irregular fuzzy graph as follows.

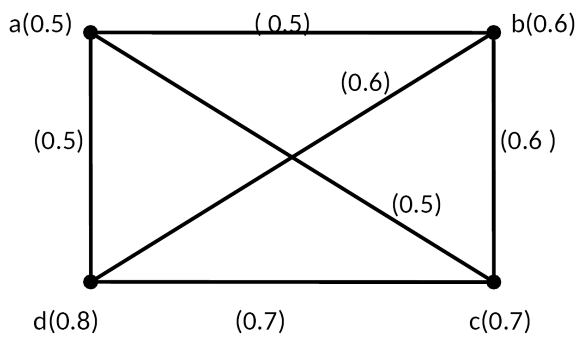
Definition 3.3: Let G be a complete fuzzy graph. A complete fuzzy graph G is said to be totally regular if each vertex has a same total degree. If possible since each vertex has a same point value.

Figure 3 Totally regular fuzzy graph



Definition 3.4: Let G be a complete fuzzy graph. A complete fuzzy graph G is said to be totally irregular if each vertex has a distinct total degree.

Figure 4 Totally irregular fuzzy graph



Remark 3.5: Every total degree complete fuzzy graph has a complete regular fuzzy graph, but converse part is not true.

Now, restrained dominating set and restrained domination number is defined below.

Definition 3.6: A subset S of V of a fuzzy graph G is said to be restrained dominating set of G if every vertex $v \in V - S$ is adjacent to at least one vertex in $u \in S$ and another vertex $v \in V - S$ such that u dominates v. The restrained domination number $\gamma_{fr}(G)$ of G is the minimum cardinality taken over all restrained fuzzy dominating sets in G.

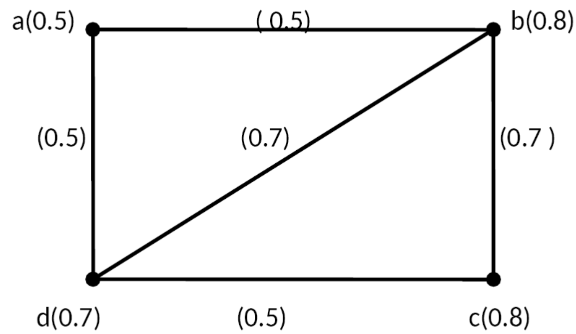
Here, we defined restrained complete domination number and established many interesting properties on them.

Definition 3.7: Let G be a fuzzy graph. A set $S \subseteq V$ is a restrained complete dominating set of G if every vertex in $v \in S$, $N_G(S) = V - S$ is a complete domination set such that u dominates v and $V - S$ has no isolated vertex. The minimum cardinality of a restrained complete domination set is the restrained complete domination number of G is denoted by $\gamma_{Frn}(G)$.

Lemma 3.8: For any fuzzy graph $G = k_n$ is a restrained complete dominate set with $\gamma_{rn}(G) = [n - (n - 1)] = 1$ if $G \cong K_n$ for all $n = 3, 4, \ldots, n$ since $|N_G[V]| = |N_G(S)| \cup| |S| = (n - 1) + 1 = n$ that is $|N_G(V)| = |S'| \cup |S| = (n - 1) + 1 = n$.

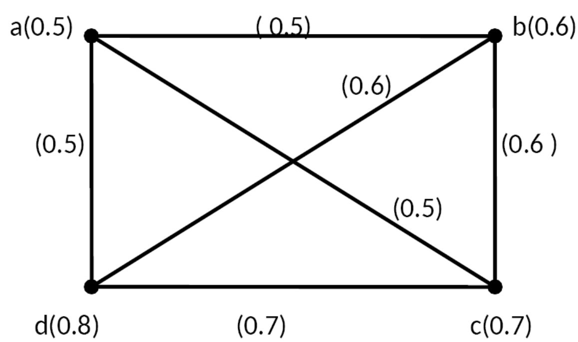
Lemma 3.9: For any fuzzy graph $G = (K_4 - e)$ is not a restrained dominating set. If $S = \{u, v\}$, $N(u) = \{v, u_i\}$, $N(v) = \{u, v_i, u_i\}$, $N(u_i) = \{v, u, v_i\}$ and $N(v_i) = \{v, u_i\}$ where u_i, v_i are neighbours of u and v respectively, hence $N(u_i) \cap N(v_i) \neq S$ by definition, it is not a restrained complete dominating by figure.

Figure 5 Fuzzy graph



Lemma 3.10: For any fuzzy graph $G = K_4$ is a restrained complete dominating set. If $S = \{a\} = 0.5$, $N(S) = \{b, c, d\}$, $N(b) = \{a, c, d\}$, $N(c) = \{b, a, d\}$, $N(d) = \{b, c, a\}$, it is a restrained complete dominating set and $\gamma_{rn}(G) = [n - (n - 1)] = 1$.

Figure 6 Fuzzy graph



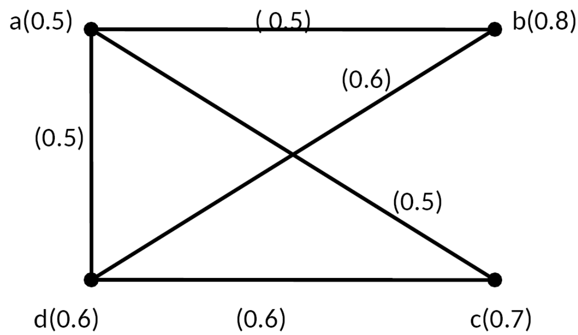
Lemma 3.11: For any fuzzy graph G. Let S be a restrained complete dominating set if there exists vertices u and v such that $N(V - S) = \{S, V - S\}$ and $\cap \{N(V - S)\} = S$.

Proof: For any fuzzy graph G if there exists u and v such that and $N(u) = \{v, u_i, v_i\}$ and $N(v) = \{u, u_i, v_i\}$ where i is the neighbours of the respective vertex and $\{N(u) \cap N(v)\} = \{u_i, v_i\} = V - S$ and $N(u_i) = \{S, v_i\}$, $N(v_i) = \{S, u_i\}$ then $N(V - S) = \{S, V - S\}$ and $\cap N(V - S) = S$ is a restrained complete dominating set.

Result 3.12: For any fuzzy graph $G = (K_4 - e)$ is not a restrained complete dominating set where $uv \in E$. If $S = \{u, v\}$, $N(S) = \{u_i, v_i\}$, since $N(u_i) = \{u, v\}$ and $N(v_i) = \{u, v\}$. Hence

$\{N(u_i) \cap N(v_i)\} = S$ but $N(u_i) \neq \{u, v, v_i\}$ and $N(v_i) \neq \{u, v, u_i\}$ by definition it is a complete domination. but for any graph $G = (K_4 - e)$ is a restrained complete dominating set with $\gamma_{frn}(G) = [n - (n - 2)]$ with $|M| = 1$.

Figure 7 Fuzzy graph



Corollary 3.13: For any fuzzy graph G is a restrained complete dominating set if there exists $u_i, v_i \in E$ such that $\{N(u_i \cap N(v_i))\} = S$.

Proof: The proof is obvious from the definition of restrained complete dominating set.

Lemma 3.14: For any fuzzy graph G. Let S is a restrained complete dominating set if there exists a vertices u and v such that $\{u, v\} \in E$ and $\{N(u) \cap N(v)\} = V - S$ and $\cup \{N(V - S)\} = V$.

Proof: For any fuzzy graph G. If there exists vertices u and v such that $\{u, v\} \in E$ and $N(u) = \{u_i, v_i\}$ and $N(v) = \{u_i, v_i\}$ and $\{N(u) \cap N(v)\} = \{u_i, v_i\} = V - S$ and $N(u_i) = \{u, v, v_i\}$, $N(v_i) = \{u, v, u_i\}$ which implies $\cup \{N(V - S)\} = \{u, v, u_i, v_i\} = V$ with S is a restrained complete dominating set S. □

Now, we established when a fuzzy graph G has a restrained complete dominating set.

Theorem 3.15: A fuzzy graph G has a restrained complete dominating set S if and only if $G \cong K_n$, for all $n \geq 3$.

Proof: Given G is a restrained dominating set if there exists $u \in S$ such that $N(u) = \{u_i\} = V - S$ for all $i = 1, 2, \ldots, n$ and $N(V - S) = \{u\}$ and at least one vertex u in $V - S$. Hence, by definition of restrained complete dominating set G must be every vertex in $V - S$ is adjacent to each vertices if S and each vertices of $V - S$, that is $N(V - S) = \{S, V - S\}$. Hence G is isomorphic to K_n. Since it is restrained complete domination for all $n \geq 3$. Conversely, given $G \cong K_n$, $n \geq 3$, Since there must be at least two vertices in $V - S$ and at least one vertex must be in S, since $G \cong K_n$, $N(V - S) = S$ and at least one vertex in $V - S$. Hence $N(V - S) = \{u, u_i\}$ and $N(u) = \{u_i\} = V - S$ for all $i = 1, 2, \ldots, n$. Hence G is a restrained complete dominating set.

Here, we established that every fuzzy restrained complete dominating set is not an independent dominating set.

Theorem 3.16: Every fuzzy restrained complete dominating set is not an independent dominating set with $\{u, v\} \in E$.

Proof: Given G be a fuzzy restrained dominating set if there exists vertices u and v such that $\{u, v\} \in E$ and $N(u) = \{v, u, v_i\}$ and $(N(u) \cup N(v)) = \{u_i, v_i\} = V - S$ and $\cup \{N(S)\} = \{S, V - S\} = V$. Hence $S = \{u, v\}$ for all $i = 1, 2, \ldots, n$ and $N(u_i) = \{v, u, v_i\}$, $N(v_i) = \{v, u, u_i\}$, $\{N(u_i) \cup N(v_i)\} = \{u, v\} = S$ and is restrained. Since the fuzzy graph G is complete and $N[S] = V$. Hence G is not an independent dominating set.

Now, we established the necessary and sufficient condition when a restrained complete dominating set is n-dominated.

Theorem 3.17: Every restrained complete dominating set is n-dominated if and only if there exists vertices u_i for all $i = 1, 2, \ldots, n$ such that each $u_i \in E$, $N(V - S) = \{S, V - S\}$ and $|\cup N(V - S)| = |S| = n$.

Proof: For any fuzzy graph G. If there exists vertices u_i for all $i = 1, 2, \ldots, n$ such that each $u_i \in E$ and by definition of restrained complete dominating set there exists n vertices in S such that $N[S] = V$. Hence, every vertices in $V - S$ is dominated by S. $N(u_i) = \{u_i\}$, and $\cup N(u_i) = \{u_i\} = V$ and $N(u_i) = \{S, u_i\}$, which implies $N(V - S) = \{S, V - S\}$ and $|\cap N(V - S)| = |S| = |\{u_1, u_2, \ldots, u_n\}| = n$. Hence S is n-dominated.

4 Restrained triple connected domination in fuzzy graphs

In this section, we defined restrained triple connected domination in fuzzy graph and established many interesting properties. First, we defined triple connected fuzzy graph.

Definition 4.1: A fuzzy graph G is said to be triple connected if any three vertices lie on a path in G.

Definition 4.2: A dominating set is said to be restrained dominating set if every vertex $V - S$ is adjacent to at least one vertex in S as well as another vertex in $V - S$ The minimum cardinality taken over all restrained dominating set is called the restrained domination number and is denoted by γ_{fr}.

Here, restrained triple connected domination set and restrained triple connected domination number of fuzzy graph is defined as follows.

Definition 4.3: A subset S of V of a fuzzy graph G is said to be restrained triple connected domination set, if S is a restrained dominating set and the induced subgraph $<S>$ is triple connected. The minimum cardinality taken over all restrained triple connected dominating set is called the restrained triple connected domination number of fuzzy graph and is denoted by γ_{frt} set of fuzzy graph G.

Remark 4.4: Fuzzy restrained triple connected dominating set does not exists for all graphs and if exists, then $\gamma_{frt}(G) \geq 3$.

Remark 4.5: Every fuzzy restrained triple connected domination set is a dominating set but not conversely.

Remark 4.6: Every fuzzy restrained triple connected dominating set is a connected dominating set but not conversely.

Results:

- For any cycle of order $p \geq 5$, $\gamma_{frt}(C_p) = p - 2$.
- For any complete fuzzy graph of order $p \geq 5$, $\gamma_{frt}(K_p) = 3$.
- For any complete bipartite fuzzy graph of order $p \geq 5$, $\gamma_{frt}(K_{m,n}) = 3$. (where m, $n \geq 2$ and $m + n = p$).

5 Conclusions

In this manuscript, the restrained complete domination number and triple connected domination number of fuzzy graphs have been proved. Some basic definitions and needful results had given with an example. The necessary and sufficient condition for the fuzzy graph to be complete restrained domination set have been formulated and proved. Also the relation between complete restrained domination set and n-dominated set has illustrated. Finally, triple connected domination number of a restrained complete fuzzy graph has been provided.

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