Some Connected Domination in Fuzzy Soft Graphs

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Abstract: *Let $G_{A,V}$ be fuzzy soft graph. A fuzzy soft accurate dominating set $S_a \subseteq V$ is said to be a **fuzzy soft connected accurate dominating** set if for each parameter, $\langle S_a \rangle$ is connected. The minimum fuzzy soft cardinality taken over all minimal fuzzy soft connected accurate dominating set is called fuzzy soft connected accurate domination number and is denoted by $\gamma_{fsca}(G_{A,V})$ and let $G_{A,V}$ be a fuzzy soft graph. A fuzzy soft equitable dominating set $S_e \subseteq V$ is called a **fuzzy soft connected equitable dominating set** if $\langle S_e \rangle$ is connected for each parameter in A. The minimum fuzzy soft cardinality of all minimal fuzzy soft connected equitable dominating set is called fuzzy soft connected equitable domination number and is denoted by $\gamma_{fsce}(G_{A,V})$.*

Key words:- *Fuzzy soft accurate domination , Fuzzy soft accurate domination number, fuzzy soft connected accurate domination, fuzzy soft connected accurate domination number, fuzzy soft connected equitable dominating set.*

I. INTRODUCTION

The concept of domination in fuzzy graphs was first introduced by A Somasundaram and S Somasundaram [8]. A Nagoorgani [5] developed the same concept in terms of strong arcs. The notion of fuzzy soft graphs was introduced by Sumit Mohinta and Samanta[7] and later on Muhammed Akram and Saira Nawas[6] introduced different types of fuzzy soft graphs and their properties. S.Revathy and C.V.R Harinarayanan[4] developed the concept Connected equitable domination in fuzzy graphs. P.Gladys and C.V.R Harinarayanan[11] introduced the concept of accurate domination in fuzzy graphs. T K Mathew varkey and Rani Rajeevan[9][10] introduced the concept of domination in fuzzy soft graphs and fuzzy soft connected domination in 2017.

In this paper we introduce domination parameters such as Fuzzy soft accurate domination, Fuzzy soft accurate domination number, fuzzy soft connected accurate domination, fuzzy soft connected accurate domination number and fuzzy soft connected equitable dominating set.

II. PRELIMINARIES

Definition 2.1 [3] Assume X be a universal set, S be the set of parameters and $P(X)$ denote the power set of X. If there is a mapping $F : S \to P(X)$, then we call the pair (F, S), a ***soft set*** over X.

Definition 2.2 [3] Let X be a universal set, S be the set of parameters and $E \subset S$. If there is a mapping $F : E \to I^X$, I^X be the set of all fuzzy subsets of S, then we say that (F, E) is a ***fuzzy soft set*** over X.

Definition 2.3 [7] Let $V = \{x_1, x_2, x_3, \cdots x_n\}$ (non empty set) E (parameters set) and $A \subseteq E$. Also let

(i) $\rho : A \to F(V)$, collection of all fuzzy subsets in V and each element e of A is mapped to $\rho(e) = \rho_e$ (say) and $\rho_e : V \to [0,1]$, each element x_i is mapped to $\rho_e(x_i)$ and we call (A, ρ), a fuzzy soft vertex.

(ii) $\mu : A \to F(V \times V)$, collection of all fuzzy subsets in $V \times V$, which mapped each element e to $\mu(e) = \mu_e$ (say) and $\mu_e : V \times V \to [0,1]$, which mapped each element (x_i, x_j) to $\mu_e(x_i, x_j)$, and we call (A, μ) as a fuzzy soft edge.

Then $((A, \rho), (A, \mu))$, is called a ***fuzzy soft graph*** if and only if $\mu_e(x_i, x_j) \le \rho_e(x_i) \wedge \rho_e(x_j)\ \forall e \in A$ and $\forall i, j = 1,2,3,\cdots n$,this fuzzy soft graph is denoted by $G_{A,V}$.

Definition2.4[6] A fuzzy soft graph $H_{A,V}(\tau_e, \sigma_e)$ is called a ***fuzzy soft sub graph*** of $G_{A,V}(\rho_e, \mu_e)$ if $\forall e \in A$ $\tau_e(x_i) \le \rho_e(x_i)\ \forall x_i \in V$ and $\sigma_e(x_i, x_j) \le \mu_e(x_i, x_j)\ \forall x_i, x_j \in V$.

Definition2.5 [6] A fuzzy soft graph $G_{A,V}$ is called a ***complete fuzzy soft graph*** if $\mu_e(x_i, x_j) = \rho_e(x_i) \wedge \rho_e(x_j)\ \forall x_i, x_j \in \rho^*, e \in A.$

Definition2.6 [6] Let $G_{A,V}$ be a fuzzy soft graph. Then the ***order*** of $G_{A,V}$ is defined as $O(G_{A,V}) = \sum_{e_i \in A}\left(\sum_{x_i \in V} \rho_e(x_i)\right)$ and ***size*** of $G_{A,V}$ is defined as $S(G_{A,V}) = \sum_{e_i \in A}\left(\sum_{x_i, x_j \in V} \mu_e(x_i, x_j)\right)$ and the ***degree*** of a vertex x_i is defined as $d_{(G_{A,V})}(x_i) = \sum_{e_i \in A}\left(\sum_{x_j \in V\ x_i \ne x_j} \mu_e(x_i, x_j)\right)$.

Definition 2.7 [9] A fuzzy soft sub graph $H_{A,V}(\tau_e, \sigma_e)$ is said to be an ***induced fuzzy soft graph*** if $\forall e \in A$ $\sigma_e(x_i, x_j) = \tau_e(x_i) \wedge \tau_e(x_j) \wedge \mu_e(x_i, x_j)\ \forall x_i, x_j \in V$ and is denoted by $\langle \tau_e \rangle$. In other words a fuzzy soft sub graph induced by τ_e is the maximal fuzzy soft sub graph that has a fuzzy soft vertex set τ_e.

Definition 2.8 [9] A ***path*** of length 'n' in a fuzzy soft graph is a sequence of distinct vertices $x_1, x_2, x_3, \ldots. x_n$ such that $\forall e \in A$ and $\mu_e(x_{i-1}, x_i) > 0$ *and* $\forall i = 1,2,3,\ldots, n$.

Definition 2.9 [9] The fuzzy soft cardinality of a fuzzy soft subset S of V is $\sum_{e \in A}\left(\sum_{x_i \in S} \rho_e(x_i)\right)$.

Definition2.10[9] Let $G_{A,V}$ be a fuzzy soft graph and let x_i and x_j be two vertices of $G_{A,V}$. If $\mu_e(x_i, x_j) \le \rho_e(x_i) \wedge \rho_e(x_j)$ for each parameter $e \in A$, then we say that x_i dominates x_j in $G_{A,V}$. A subset S of V is called a ***fuzzy soft dominating set*** if for every $x_j \in V - S$, there exist a vertex $x_i \in S$ such that x_i dominates x_j.

Definition 2.11[9] A fuzzy soft dominating set S of a fuzzy soft graph $G_{A,V}$ is said to be a ***minimal fuzzy soft dominating set*** if for each parameter $e \in A$, deletion of an element from S is not a fuzzy soft dominating set.

Definition 2.12[9] The minimum cardinality of all minimal fuzzy soft dominating set is called the ***fuzzy soft domination number*** and is denoted by $\gamma_{fs}(G_{A,V})$.

Definition 2.13[10] Let $G_{A,V}$ be a fuzzy soft graph and $S \subseteq V$ be a fuzzy soft dominating set. If $\langle S \rangle$ is connected for each parameter, then S is called ***fuzzy soft connected dominating set***. The minimum fuzzy soft cardinality of a fuzzy soft connected dominating set is called the ***fuzzy soft connected domination number*** and is denoted by $\gamma_{fsc}(G_{A,V})$.

III. 1 CONNECTED ACCURATE DOMINATION IN FUZZY SOFT GRAPHS

Definition 3.1.1 Let $G_{A,V}$ be fuzzy soft graph. A fuzzy soft dominating set $S \subseteq V$ is said to be a ***fuzzy soft accurate dominating set*** if for each parameter, its complement $V - S$ has no fuzzy soft dominating set of same fuzzy soft cardinality of the fuzzy soft accurate dominating set. The minimum fuzzy soft cardinality taken over all minimal fuzzy soft accurate dominating set is called fuzzy soft accurate domination number and is denoted by $\gamma_{fsa}(G_{A,V})$.

Definition 3.1.2 Let $G_{A,V}$ be fuzzy soft graph. A fuzzy soft accurate dominating set $S_a \subseteq V$ is said to be a ***fuzzy soft connected accurate dominating*** set if for each parameter, $\langle S_a \rangle$ is connected. The minimum fuzzy soft cardinality taken over all minimal fuzzy soft connected accurate dominating set is called fuzzy soft connected accurate domination number and is denoted by $\gamma_{fsca}(G_{A,V})$.

Remark 3.1.3 Every fuzzy soft accurate dominating set is not a fuzzy soft connected accurate dominating set.

Theorem 3.1.4 If $G_{A,V}$ be a fuzzy soft connected graph with more than 2 vertices for each parameter, then $\gamma_{fs}(G_{A,V}) \leq \gamma_{fsa}(G_{A,V}) \leq \gamma_{fsca}(G_{A,V})$.

Proof: Let $G_{A,V}$ be a fuzzy soft connected graph with more than 2 vertices and let $S \subseteq V$ be a minimal fuzzy soft dominating set having minimum fuzzy soft cardinality. So $\gamma_{fs}(G_{A,V})$ is the fuzzy soft cardinality of S.

First we prove $\gamma_{fs}(G_{A,V}) \leq \gamma_{fsa}(G_{A,V})$.

Case (i) $V - S$ has no dominating set with same fuzzy soft cardinality of S, then $\gamma_{fsa}(G_{A,V})$ is the fuzzy soft cardinality of S and is equal to $\gamma_{fsa}(G_{A,V})$.

Case (ii) $V - S$ has dominating set with same fuzzy soft cardinality of S ,then we know that every fuzzy soft accurate dominating set is also a fuzzy soft dominating set. So we get $\gamma_{fs}(G_{A,V}) \leq \gamma_{fsa}(G_{A,V})$.

Next we prove $\gamma_{fsa}(G_{A,V}) \leq \gamma_{fsca}(G_{A,V})$.

Suppose $S_a \subseteq V$ be a fuzzy soft accurate dominating set in $G_{A,V}$.

Case (i) If $\langle S_a \rangle$ is connected, then S_a is a fuzzy soft connected accurate dominating set. Thus fuzzy soft cardinality of S_a is equal to $\gamma_{fsa}(G_{A,V}) = \gamma_{fsca}(G_{A,V})$.

Case (ii) If $\langle S_a \rangle$ is connected, then fuzzy soft cardinality of S_a is equal to $\gamma_{fsa}(G_{A,V}) < \gamma_{fsca}(G_{A,V})$. So we get $\gamma_{fsa}(G_{A,V}) \leq \gamma_{fsca}(G_{A,V})$.

Combining above two results we get $\gamma_{fs}(G_{A,V}) \leq \gamma_{fsa}(G_{A,V}) \leq \gamma_{fsca}(G_{A,V})$.

Theorem 3.1.5 If $G_{A,V}$ be a fuzzy soft connected graph with more than 2 vertices for each parameter, then $\gamma_{fsc}(G_{A,V}) \leq \gamma_{fsca}(G_{A,V})$.

Proof: Let $G_{A,V}$ be a fuzzy soft connected graph with more than 2 vertices and let $S_c \subseteq V$ be a minimal fuzzy soft connected dominating set having minimum fuzzy soft cardinality. So $\gamma_{fsc}(G_{A,V})$ is the fuzzy soft cardinality of S_c.

If $V - S_c$ has no fuzzy soft connected dominating set with same fuzzy soft cardinality of S_c, then S_c is a fuzzy soft connected accurate dominating set. So $\gamma_{fsc}(G_{A,V}) = \gamma_{fsca}(G_{A,V})$.

Also we know that every connected accurate dominating set is a fuzzy soft connected dominating set in $G_{A,V}$. Hence $\gamma_{fsc}(G_{A,V}) \leq \gamma_{fsca}(G_{A,V})$.

Theorem 3.1.6 If $G_{A,V}$ be a fuzzy soft connected graph with more than 2 vertices for each parameter and $H_{A,V}$ be any fuzzy soft connected accurate spanning sub graph of the fuzzy soft graph $G_{A,V}$, then $\gamma_{fsca}(G_{A,V}) \leq \gamma_{fsca}(H_{A,V})$.

Proof: Let $G_{A,V}$ be any fuzzy soft connected graph with more than 2 vertices for each parameter and $H_{A,V}$ be any fuzzy soft connected accurate spanning subgraph of $G_{A,V}$. Since every connected accurate dominating set of fuzzy soft spanning subgraph is also a fuzzy soft connected accurate dominating set of $G_{A,V}$, we have $\gamma_{fsca}(G_{A,V}) \leq \gamma_{fsca}(H_{A,V})$.

Theorem 3.1.7 Let $G_{A,V}$ be a fuzzy soft complete graph with more than 2 vertices for each parameter and all vertices having unequal fuzzy soft cardinality, then $\gamma_{fsca}(G_{A,V}) = \wedge\left[\sum_{e \in A} \rho_e(x_i)\ \forall\ x_i \in V\right]$.

Proof: Suppose that $G_{A,V}$ be a fuzzy soft complete graph with more than 2 vertices and all vertices having unequal fuzzy soft cardinality. Since $G_{A,V}$ is complete each vertex is adjacent to all other vertices and since all vertices having unequal fuzzy soft cardinality, each single vertex set is a fuzzy soft connected accurate dominating set. Then by definition of fuzzy soft accurate domination number, $\gamma_{fsca}(G_{A,V})$ is the minimum fuzzy soft cardinality of a single vertex set. Hence $\gamma_{fsca}(G_{A,V}) = \wedge\left[\sum_{e \in A} \rho_e(x_i)\ \forall\ x_i \in V\right]$.

Corollary 3.1.8 In a fuzzy soft complete graph with all vertices having unequal fuzzy soft cardinality $\gamma_{fs}(G_{A,V}) = \gamma_{fsa}(G_{A,V}) = \gamma_{fsca}(G_{A,V})$.

Theorem 3.1.9 If $G_{A,V}$ is a path of length $n\,(n \geq 3)$ and if there exist a fuzzy soft connected accurate dominating set, then it contains exactly $n-2$ elements.

Proof: Let $G_{A,V}$ be a path of length n. Let S_a be a fuzzy soft accurate dominating set. But for a fuzzy soft connected accurate dominating set, $\langle S_a \rangle$ is connected. Since $G_{A,V}$ is a path, S_a must have exactly $n-2$ vertices. That is $S_a = V - \{x_1, x_n\}$, where x_1 & x_n are the end vertices of the fuzzy soft path in $G_{A,V}$. Hence if there exist fuzzy soft connected accurate dominating sets in $G_{A,V}$, then it must contains exactly $n-2$ elements.

Theorem 3.1.10 If $G_{A,V}$ is a fuzzy soft path of length n and there exist a fuzzy soft connected accurate dominating set in $G_{A,V}$, then $\gamma_{fsca}(G_{A,V}) = \sum_{e\in A}\sum_{x_i\in V-\{x_1,x_n\}} \rho_e(x_i)$.

Proof: By above theorem we get fuzzy soft connected accurate dominating set in fuzzy soft path $G_{A,V}$ contains exactly $n-2$ elements. That is the fuzzy soft connected accurate dominating set contains all the vertices in V except x_1 & x_n. But by definition of fuzzy soft connected accurate domination number, $\gamma_{fsca}(G_{A,V})$ is the fuzzy soft cardinality of elements in fuzzy soft connected accurate dominating set. Hence we get $\gamma_{fsca}(G_{A,V}) = \sum_{e\in A}\sum_{x_i\in V-\{x_1,x_n\}} \rho_e(x_i)$.

Theorem 3.1.11 If $G_{A,V}$ be a fuzzy soft cycle containing n vertices $(n \geq 3)$ and if there exist a fuzzy soft connected accurate dominating set then it contains exactly $n-2$ vertices.
Proof: Similar to theorem 3.1.10.

III.2 *FUZZY SOFT CONNECTED EQUITABLE DOMINATION*

Definition 3.2.1 Let $G_{A,V}$ be a fuzzy soft graph. A fuzzy soft equitable dominating set $S_e \subseteq V$ is called a ***fuzzy soft connected equitable dominating set*** if $\langle S_e \rangle$ is connected for each parameter in A. The minimum fuzzy soft cardinality of all minimal fuzzy soft connected equitable dominating set is called fuzzy soft connected equitable domination number and is denoted by $\gamma_{fsce}(G_{A,V})$.

Theorem 3.2.2 Every fuzzy soft connected equitable dominating set is a fuzzy soft equitable dominating set.
Proof: Suppose that S_{ce} is a fuzzy soft connected equitable dominating set. Then for every $x_j \in V - S_{ce}$ there exist a vertex $x_i \in S_{ce}$ such that x_i is adjacent to x_j, $|\deg(x_i) - \deg(x_j)| \leq 1$ for each parameter in A and $\langle S_{ce} \rangle$ is connected. Hence S_{ce} is a fuzzy soft equitable dominating set.

Remark 3.2.3 Converse of the above theorem need not be true.

Theorem 3.2.4 If $G_{A,V}$ is a fuzzy soft regular graph then $\gamma_{fsce}(G_{A,V}) = \gamma_{fsc}(G_{A,V})$.

Proof: Suppose that $G_{A,V}$ is a fuzzy soft regular graph. Then each vertex has same degree, say t for each parameter in A. Let S_c be a minimum fuzzy soft connected dominating set. So $\gamma_{fsc}(G_{A,V})$ is the fuzzy soft cardinality of S_c. Since S_c is a fuzzy soft connected dominating set, for each $x_j \in V - S_{ce}$ there exist a vertex $x_i \in S_c$ such that x_i is adjacent to x_j for each parameter in A. Also since $G_{A,V}$ is fuzzy soft regular $\deg(x_i) = \deg(x_j) = t$ for each parameter in A. There fore $|\deg(x_i) - \deg(x_j)| = 0 < 1$. Hence S_{ce} is a fuzzy soft connected equitable dominating set in $G_{A,V}$. So that $\gamma_{fsce}(G_{A,V}) \leq \gamma_{fsc}(G_{A,V})$. But $\gamma_{fsce}(G_{A,V}) \geq \gamma_{fsc}(G_{A,V})$. Hence $\gamma_{fsce}(G_{A,V}) = \gamma_{fsc}(G_{A,V})$.

Theorem 3.2.5 For any fuzzy soft connected graph $G_{A,V}$, $\gamma_{fs}(G_{A,V}) \leq \gamma_{fse}(G_{A,V}) \leq \gamma_{fsce}(G_{A,V})$.

Proof : Since any fuzzy soft connected equitable dominating set is a fuzzy soft equitable dominating set and any fuzzy soft equitable dominating set is a fuzzy soft dominating set, we have $\gamma_{fs}(G_{A,V}) \leq \gamma_{fse}(G_{A,V}) \leq \gamma_{fsce}(G_{A,V})$.

Theorem 3.2.6 For any fuzzy soft connected graph $G_{A,V}$, $\gamma_{fsc}(G_{A,V}) \leq \gamma_{fsce}(G_{A,V})$.

Proof: Since any fuzzy soft connected equitable dominating set is a fuzzy soft connected dominating set and from the definition of fuzzy soft connected equitable dominating set, $\gamma_{fsc}(G_{A,V}) \leq \gamma_{fsce}(G_{A,V})$.

Theorem 3.2.7 Any fuzzy soft connected equitable dominating set S_{ce} is a minimal fuzzy soft connected equitable dominating set if and only if for each $x_i \in S_{ce}$ one of the following two conditions holds.

(i) x_i is not adjacent to any vertex in S_{ce} .

(ii) There exist a vertex $x_s \in V - S_{ce}$ such that $N(x_i) \cap S_{ce} = \{x_s\}$.

Proof: Let S_{ce} be a minimal fuzzy soft connected equitable dominating set and $x_i \in S_{ce}$. Then $S_{ce} - \{x_i\}$ is not a connected fuzzy soft equitable dominating set and hence there exist $x_j \in V - (S_{ce} - \{x_i\})$ such that x_j is not fuzzy soft dominated by any vertex of $S_{ce} - \{x_i\}$.

Case (i) If $x_i = x_j$ then x_i is not adjacent to any vertex of S_{ce} .

Case (ii) If $x_i \neq x_j$, since $x_i \in S_{ce}$, there exist a vertex $x_s \in V - S_{ce}$ such that $N(x_i) \cap S_{ce} = \{x_s\}$.

Conversely suppose that S_{ce} is a fuzzy soft connected equitable dominating set and for every $x_i \in S_{ce}$, one of the statements (i) or (ii) holds. Now we show that S_{ce} is a minimal fuzzy soft connected equitable dominating set. Suppose on the contrary that S_{ce} is not a minimal fuzzy soft connected equitable dominating set. Then there exist a vertex $x_i \in S_{ce}$ such that $S_{ce} - \{x_i\}$ is a fuzzy soft connected equitable dominating set. Hence x_i is adjacent to at least one vertex of $S_{ce} - \{x_i\}$, which is a contradiction to (i). Then x_i must satisfy (ii). That is there exist a vertex $x_s \in V - S_{ce}$ such that $N(x_i) \cap S_{ce} = \{x_s\}$. Since S_{ce} is a fuzzy soft connected equitable dominating set, by definition for each parameter in A and for each vertex $x_s \in V - S_{ce}$, there exist some vertex $x_t \in S_{ce}$ such that x_t is adjacent to x_s and x_t & x_s are degree equitable and $\langle S_{ce} \rangle$ is connected. Since $x_i \in S_{ce}$ and x_i is connected to x_s and x_t, $N(x_i) \cap S_{ce}$ contains more than one element, which is a contradiction to (ii). Hence S_{ce} is a minimal fuzzy soft connected equitable dominating set.

Theorem 3.2.8 Let $G_{A,V}$ be a fuzzy soft connected graph having equitable dominating sets and $H_{A,V}$ is a connected spanning sub-graph in $G_{A,V}$. Then $\gamma_{fsce}(G_{A,V}) \leq \gamma_{fsce}(H_{A,V})$.

Proof: Let $G_{A,V}$ be a fuzzy soft connected graph having equitable dominating sets and $H_{A,V}$ is a connected spanning sub-graph in $G_{A,V}$ .Suppose that S_{ce} be the minimum fuzzy soft connected equitable dominating set in

$H_{A,V}$. Then every vertex in S_{ce} is fuzzy soft connected equitable with all the vertices in $V(H_{A,V}) - S_{ce}$. . There fore S_{ce} is connected equitable dominating set in $G_{A,V}$.

Hence $\gamma_{fsce}(G_{A,V}) \leq \gamma_{fsce}(H_{A,V})$.

IV. CONCLUSION

In this paper we defined two connected domination parameters such as fuzzy soft connected accurate domination, fuzzy soft connected equitable domination, which are very useful for solving wide range of problems.

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