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Total Domination in Uniform Single Valued Neutrosophic Graph

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Abstract. In graph theory, the neutrosophic graph is a new extension of the intuitionistic fuzzy graph and fuzzy graph. It offers greater accuracy and flexibility in scheduling and implementing numerous real-life issues. The introduction of neutrosophic graphs has opened up an excellent opportunity to portray real-world situations with incomplete and ambiguous information. These neutrosophic graph models are used in many industrial and scientific domains to simulate various problems. This article offers a new approach for calculating the total dominating set of a given single-valued neutrosophic graph using neutrosophic strong arcs. An example is illustrated for calculating the total dominating sets of single-valued neutrosophic graphs. Moreover, certain observations related to uniform single-valued neutrosophic graphs are covered and we also suggest an application of a total dominating set in single-valued neutrosophic graphs in the real world.

Keywords: Domination; Total domination; Single-valued neutrosophic graphs; Neutrosophic strong arcs.

1. **Introduction**

While dealing with uncertain situations and imperfect knowledge, certain powerful mathematical techniques are required. Graph theory is a mathematical method that successfully manages massive amounts of data. If there is any ambiguity, fuzzy graphs are the ideal tool to use. Graph theory is particularly intriguing because of its potential applications in management, social, computer and information sciences, and data handling. Zadeh's [13] fuzzy set is one of the best solutions for dealing with uncertain conditions and unknown data. A fuzzy set consists of objects defined by a membership function that allots each element a degree of membership ranging from 0 to 1. Rosenfeld [9] examined fuzzy graphs (FG) in-depth, revealing some of their core properties. FG are essential because they are better at dealing with ambiguity; nevertheless, Atanassov [1] noted that fuzzy sets can only handle one-sided uncertainty, which is unsatisfactory since human nature is not limited to yes or no answers, which is why he proposed the idea of intuitionistic fuzzy set. An element's membership function and non-membership function characterize this intuitionistic fuzzy set. As per Atanassov, the sum of the membership and non-membership functions does not exceed one. Later, F. Smarandache [11] introduced the neutrosophic set. The neutrosophic set helps to handle vague, inconsistent, and uncertain data in real-world situations. H. Wang [12] introduced single-valued neutrosophic sets (S-VNS) to simplify their use in real-world situations. The S-VNS broadens intuitionistic fuzzy sets by employing three separate membership functions, each with values between 0 and 1. Later, Broumi [2] et al. proposed the idea of single-valued neutrosophic graph (S-VNG).

Among various dominations, E J Cockayne [4] proposed total domination in graph theory. Parvati [8] et al. presented the concept of domination in intuitionistic fuzzy graphs (IFG) using strong arcs, and M. Mullai [7] put forward the idea of domination in neutrosophic graphs using a different method. Until now, no studies have been carried out on total domination in a S-VNG using the idea of neutrosophic-strong arcs.

In this paper, we implemented the strong arc concept of Parvati et al. to determine the dominating set (D-Set) and total dominating set (TD-Set) of a S-VNG. The paper is structured as follows:

In Section 2, We discussed fundamental definitions pertinent to our research. In Section 3, A new idea called neutrosophic-strong arc is defined and we developed a new method for determining TD-Set of a S-VNG. Some theorems related to TD-Set in a uniform S-VNG are also discussed in this section. Section 4 contains an application of TD-Set of a S-VNG and the paper's conclusion is finally provided in section 5.

2. Preliminaries

This section will cover the fundamental concepts of S-VNG essential for our study. In this paper, $G^* = (V, E)$ denotes a simple graph.

Definition 2.1. [5] A FG on G^* is denoted as $G = (\delta, \eta)$; where δ is a fuzzy subset of V and η is a symmetric fuzzy relation on δ.

i.e., $\delta : V \to [0, 1]$ and $\eta : E \to [0, 1]$ such that

$\eta(h, l) \leq \delta(h) \wedge \delta(l)\ \forall h,\ l \in V$ where hl is an arc betwixt the vertices h and l.

Definition 2.2. [2] An IFG is of the form $G = (V, E)$ where

(1) $V = \{h_1, h_2, ..., h_n\}$ such that $\tau_1 : V \to [0, 1]$ and $\nu_1 : V \to [0, 1]$ denotes the degree of membership and degree of non-membership of an element $h_i \in V$ respectively, and

$0 \leq \tau_1(h_i) + \nu_1(h_i) \leq 1\ \forall h_i \in V (i = 1, 2, ..., n)$.

(2) $E \subseteq V \times V$ where $\tau_2 : E \to [0, 1]$ and $\nu_2 : E \to [0, 1]$ are such that

$\tau_2(h_i, h_j) \leq \tau_1(h_i) \wedge \tau_1(h_j)$

$\nu_2(h_i, h_j) \geq \nu_1(h_i) \vee \nu_1(h_j)$
$0 \leq \tau_2(h_i, h_j) + \nu_2(h_i, h_j) \leq 1 \ \forall (h_i, h_j) \in E(i = 1, 2, ..., n).$

Definition 2.3. [2] A S-VNG on $G^* = (V, E)$ is defined to be $G = (\phi, \psi)$ where

(1) The functions $T_\phi : V \to [0, 1]$, $I_\phi : V \to [0, 1]$ and $F_\phi : V \to [0, 1]$ indicates the degree of truth-membership function, indeterminacy-membership function and falsity-membership function of an element $h_j \in V$ and
$0 \leq T_\phi(h_j) + I_\phi(h_j) + F_\phi(h_j) \leq 3 \ \forall h_j \in V.$

(2) The functions $T_\psi : E \to [0, 1]$, $I_\psi : E \to [0, 1]$ and $F_\psi : E \to [0, 1]$ are defined by
$T_\psi(h_j, h_k) \leq T_\phi(h_j) \wedge T_\phi(h_k)$
$I_\psi(h_j, h_k) \geq I_\phi(h_j) \vee I_\phi(h_k)$
$F_\psi(h_j, h_k) \geq F_\phi(h_j) \vee F_\phi(h_k)$ and
$0 \leq T_\psi(h_j, h_k) + I_\psi(h_j, h_k) + F_\psi(h_j, h_k) \leq 3 \ \forall (h_j, h_k) \in E; (j, k = 1, 2, ..., n).$

Definition 2.4. [2] A S-VNG $G = (\phi, \psi)$ is a Complete S-VNG if
$T_\psi(h_j, h_k) = T_\phi(h_j) \wedge T_\phi(h_k)$
$I_\psi(h_j, h_k) = I_\phi(h_j) \vee I_\phi(h_k)$
$F_\psi(h_j, h_k) = F_\phi(h_j) \vee F_\phi(h_k) \ \forall h_j, h_k \in V.$

Definition 2.5. [6] A S-VNG $G = (\phi, \psi)$ is a bi-partite if ϕ can be partitioned into two non-empty sets ϕ_1 and ϕ_2 such that

(1) $T_\psi(h_i, l_j) = 0$, $I_\psi(h_i, l_j) = 0$, $F_\psi(h_i, l_j) = 0$ if $(h_i, l_j) \in \phi_1$ or $(h_i, l_j) \in \phi_2$

(2) $T_\psi(h_i, l_j) > 0$, $I_\psi(h_i, l_j) > 0$, $F_\psi(h_i, l_j) > 0$ if $h_i \in \phi_1$ and $l_j \in \phi_2$ (OR)
$T_\psi(h_i, l_j) = 0$, $I_\psi(h_i, l_j) > 0$, $F_\psi(h_i, l_j) > 0$ if $h_i \in \phi_1$ and $l_j \in \phi_2$ (OR)
$T_\psi(h_i, l_j) > 0$, $I_\psi(h_i, l_j) = 0$, $F_\psi(h_i, l_j) > 0$ if $h_i \in \phi_1$ and $l_j \in \phi_2$ (OR)
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$T_\psi(h_i, l_j) > 0$, $I_\psi(h_i, l_j) = 0$, $F_\psi(h_i, l_j) = 0$ if $h_i \in \phi_1$ and $l_j \in \phi_2$.

Definition 2.6. [6] A bipartite S-VNG is said to be Complete if it satisfies all the conditions of a Complete S-VNG.

Definition 2.7. [3] Let $G = (\phi, \psi)$ be a S-VNG, $\phi = (T_\phi, I_\phi, F_\phi)$ is a single valued neutrosophic vertex set of G and $\psi = (T_\psi, I_\psi, F_\psi)$ is a single valued neutrosophic edge set of G. Let $\phi = \{h \in V | T_\phi(h) > 0, I_\phi(h) > 0, F_\phi(h) > 0\}$. Then G is a uniform-single valued neutrosophic graph (U-SVNG) of level (k_1, k_2, k_3) if

(1) $T_\psi(h_i, l_j) = k_1$, $I_\psi(h_i, l_j) = k_2$, $F_\psi(h_i, l_j) = k_3 \ \forall (h_i, l_j) \in E$

(2) $T_\phi(h_i) = k_1$, $I_\phi(h_i) = k_2$, $F_\phi(h_i) = k_3$ where $0 < k_1, k_2, k_3 \leq 1$.

Definition 2.8. [6] Let $G = (\phi, \psi)$ be a S-VNG and $h, l \in \phi$. Then,

(1) $T - strength$ of connectedness among h and l is termed as
$T_{\psi}^{\infty}(h, l) = \vee\{T_{\psi}^{n}(h, l)|n = 1, 2, ..., k\}$; where
$T_{\psi}^{n}(h, l) = T_{\psi}(h, a_1) \wedge T_{\psi}(a_1, a_2), .. \wedge T_{\psi}(a_{n-1}, l)$; $h, a_1, a_2, ..., a_{n-1}, l \in V$ and $n = \{1, 2, ..., k\}$.

(2) $I - strength$ of connectedness among h and l is termed as
$I_{\psi}^{\infty}(h, l) = \wedge\{I_{\psi}^{n}(h, l)|n = 1, 2, ..., k\}$; where
$I_{\psi}^{n}(h, l) = I_{\psi}(h, a_1) \vee I_{\psi}(a_1, a_2), .. \vee I_{\psi}(a_{n-1}, l)$; $h, a_1, a_2, ..., a_{n-1}, l \in V$ and $n = \{1, 2, ..., k\}$.

(3) $F - strength$ of connectedness among h and l is termed as
$F_{\psi}^{\infty}(h, l) = \wedge\{F_{\psi}^{n}(h, l)|n = 1, 2, ..., k\}$; where
$F_{\psi}^{n}(h, l) = F_{\psi}(h, a_1) \vee F_{\psi}(a_1, a_2), .. \vee F_{\psi}(a_{n-1}, l)$; $h, a_1, a_2, ..., a_{n-1}, l \in V$ and $n = \{1, 2, ..., k\}$.

Definition 2.9. [10] Let $G = (\phi, \psi)$ be a S-VNG. The vertex cardinality of G is defined as:
$|V| = \sum \left(\frac{1+T_{\phi}(h_i)+I_{\phi}(h_i)-F_{\phi}(h_i)}{2}\right)$.

Definition 2.10. [10] Let $G = (\phi, \psi)$ be a S-VNG. The edge cardinality of G is defined as:
$|E| = \sum \left(\frac{1+T_{\psi}(h_i,l_j)+I_{\psi}(h_i,l_j)-F_{\psi}(h_i,l_j)}{2}\right)$.

3. Total Domination in a S-VNG

Definition 3.1. An arc $h_i l_j$ of a S-VNG $G = (\phi, \psi)$ is a neutrosophic-strong arcs (N_{SA}) if
$T_{\psi}(h_i, l_j) \geq T_{\psi}^{\infty}(h_i, l_j)$
$I_{\psi}(h_i, l_j) \leq I_{\psi}^{\infty}(h_i, l_j)$ and
$F_{\psi}(h_i, l_j) \leq F_{\psi}^{\infty}(h_i, l_j)$ where $h_i, l_j \in V$.

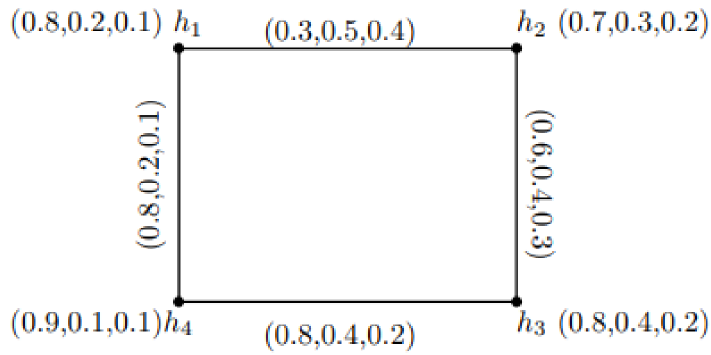
Definition 3.2. Let $G = (\phi, \psi)$ be a S-VNG and $h, l \in V$, then the vertex h dominates l if hl is a N_{SA} in G.

Definition 3.3. Let $G = (\phi, \psi)$ be a S-VNG and $h \in V$. Then, the neutrosophic-strong arc neighborhood vertices of the vertex h ($N_{SA}(h)$) is defined as:
$N_{SA}(h) = \{l \in V : hl$ is a neutrosophic-strong arc in G$\}$.

Definition 3.4. Let $G = (\phi, \psi)$ be a S-VNG. $S \subseteq V$ is said to be a D-Set in G if $\forall h \in V - S$, $\exists$ a $l \in S$ such that h and l are neutrosophic-strong arc neighborhood vertices in G.

Definition 3.5. A D-Set S of a S-VNG is said to be a minimal D-Set if no proper subset of S will form a D-Set in G.

The lower domination number, denoted by $\gamma_d^{'}$ is the minimum cardinality among all the minimal D-Set of G and the upper domination number, denoted by $\gamma_D^{'}$ is the maximum cardinality among all the minimal D-Set of G.



S-VNG

FIGURE 1. h_1h_4, h_2h_3, h_3h_4 are the neutrosophic-strong arcs and $N_{SA}(h_1) = \{h_4\}$, $N_{SA}(h_2) = \{h_3\}$, $N_{SA}(h_3) = \{h_2, h_4\}$, $N_{SA}(h_4) = \{h_1, h_3\}$. $A = \{h_1, h_3\}$, $B = \{h_3, h_4\}$, $C = \{h_1, h_2\}$ and $D = \{h_2, h_4\}$ are the minimal D-set and $|A| = 1.95$, $|B| = 1.95$, $|C| = 1.85$ and $|D| = 1.85$ are their corresponding cardinalities. $\gamma'_d = 1.85$ and $\gamma'_D = 1.95$. $B = \{h_3, h_4\}$ is the minimal TD-Set of fig:1 with $\gamma'_{td} = \gamma'_{TD} = 1.95$.

Definition 3.6. $S \subseteq V$ is called a TD-Set of G if every vertices in V is dominated by at least one vertex of S. Note that TD-Set is defined solely for graphs that do not contain isolated vertices..

Lower total domination number is denoted by γ'_{td} and upper total domination number is denoted by γ'_{TD}.

Example 3.7. Consider a S-VNG without isolated vertices $G = (V, E)$ as shown in fig.1

Theorem 3.8. *Let $G = (V, E)$ be a complete bi-partite S-VNG without isolated vertices. Then $\gamma'_{td} = |h| + |l|$ where h and l are two vertices with minimum cardinality among the vertex sets V_1 and V_2.*

Proof. Let $G = (V, E)$ be a complete bi-partite S-VNG without isolated vertices and also let h be the vertex with minimum cardinality in V_1 and l represent the vertex with minimum cardinality in V_2.

Since all of the vertices in the provided S-VNG meets the conditions for strong arcs, every vertices in V_2 will be dominated by a vertex in V_1.

Let $T = \{h, l\}$ is not a TD-Set of $G = (V, E)$.

Then $z \in V - \{h, l\}$ is adjacent to more than one vertex in G.

That is, z is adjacent to both h and l. This contradicts the claim that $G = (V, E)$ is a complete bi-partite S-VNG.

Thus $T = \{h, l\}$ will form a TD-Set of $G = (V, E)$ and $\gamma'_{td} = |h| + |l|$. □

Definition 3.9. A U-SVNG $G = (\phi, \psi)$ is a complete U-SVNG if

$T_\psi(h_j, h_k) = T_\phi(h_j) \wedge T_\phi(h_k)$

$I_\psi(h_j, h_k) = I_\phi(h_j) \vee I_\phi(h_k)$

$F_\psi(h_j, h_k) = F_\phi(h_j) \vee F_\phi(h_k)\ \forall h_j, h_k \in V$.

Theorem 3.10. *Let $G = (\phi, \psi)$ be a U-SVNG without isolated vertices, then for a n-cycle (C_n) graph of G with $n \geq 4$, $\gamma'_{td} = (n-2)|h_i|$; $h_i \in V$.*

Proof. Assume that the U-SVNG $G = (\phi, \psi)$ has no isolated vertices. By the definition of U-SVNG, all the edges and vertices of C_n graph will have same values. Let $S \subseteq V$ be a TD-Set C_n graph, and let $V = \{h_1, h_2, ..., h_n\}$ be the graph's vertices. Neutrosophic vertex cardinality of S in a S-VNG is given by

$|S| = \sum \left(\frac{1+T_\phi(h_i)+I_\phi(h_i)-F_\phi(h_i)}{2} \right); h_i \in V$

Claim: $\gamma'_{td} = |S| = (n-2)|h_i|; h_i \in V$.

Here, Two cases will arrive.

Case:1 $|S| \leq (n-2)|h_i|$

Let $S = \{h_1, h_2, ..., h_{n-2}\}$ be the TD-Set of the C_n graph. If S is not a minimal TD-Set, then there exist a subset of S which is able to dominate all the vertices of C_n graph. This is not possible because one vertex will remain undominated by any of the vertices in S if less than $(n-2)$ vertices are used. This implies S is a TD-Set.

Therefore $|S| = (n-2)|h_i|$.

Case:2 $|S| \geq (n-2)|h_i|$.

If possible,

When a new vertex l is added to S, $S = \{h_1, h_2, ..., h_{n-2}, l\}$ becomes the new set S. Now S has $(n-1)$ elements and it will form a TD-Set. Upon evaluating the set S, a subset of S is found that has the potential to dominate every vertices of C_n graph. Thus S is not a minimal TD-Set.

Therefore, $\gamma'_{td} \ngtr (n-2)|h_i|$.

From the two cases, we can conclude that the set S needs only $(n-2)$ vertices to dominate all the vertices of the given C_n graph.

Thus, $\gamma'_{td} = |S| = (n-2)|h_i|; h_i \in V$. □

Theorem 3.11. *If $G = (\phi, \psi)$ is a complete U-SVNG without isolated vertices, then $\gamma'_{td} = 2|h_i|$; $h_i \in V$.*

Proof. Let $G = (\phi, \psi)$ be a complete U-SVNG without isolated vertices. By the definition of U-SVNG, G's vertices and edges will have same values.

i.e,

$T_\psi(h_j, h_k) = k_1 = T_\phi(h_j) = T_\phi(h_k)$,
$I_\psi(h_j, h_k) = k_2 = I_\phi(h_j) = I_\phi(h_k)$ and
$F_\psi(h_j, h_k) = k_3 = F_\phi(h_j) = F_\phi(h_k)$ $\forall (h_j, h_k) \in E$ and $0 < k_1, k_2, k_3 \leq 1$.

A TD-Set needs minimum of 2 elements to dominate all the vertices of any graph. As there is a neutrosophic-strong arc connecting each pair of vertices of G, all of its vertices will dominate one another. Since G is a complete U-SVNG, every vertices in it will have the same values and its TD-Set only needs two elements in order to dominate the other vertices of G. As a result, the cardinality of one of its vertices is always twice the overall domination number. $\gamma'_{td} = 2|h_i|$; $h_i \in V$. □

3.1. *Observations on total domination number in a U-SVNG*

Let $G = (\phi, \psi)$ be a simple U-SVNG without isolated vertices. In this section, we will show the value of $\gamma'_{td}(G)$ for different graph classes. We denote P_n, W_n, L_n, S_n, F_n, $L_{m,n}$, $T_{m,n}$ and B_n for the Path, Wheel graph, Ladder graph, Star graph, Friendship graph, Lollipop graph, Tadpole graph and n-Book graph.

- $\gamma'_{td}(P_n) = (n-1)|h_i|$, $n \geq 3$ and $h_i \in V$.
- $\gamma'_{td}(W_n) = 2|h_i|$, $h_i \in V$.
- $\gamma'_{td}(L_n) = (2n-4)|h_i|$, $n \geq 3$ and $h_i \in V$.
- $\gamma'_{td}(S_n) = 2|h_i|$, $h_i \in V$.
- $\gamma'_{td}(F_n) = 2|h_i|$, $h_i \in V$.
- $\gamma'_{td}(L_{m,n}) = n|h_i|$, $n \geq 2$ and $h_i \in V$.
- $\gamma'_{td}(T_{m,n}) = \gamma'_{td}(C_m) + \gamma'_{td}(P_n)$, $m \geq 4$ and $n \geq 3$.
- $\gamma'_{td}(B_n) = 2|h_i|$, $n \geq 3$ and $h_i \in V$.

4. **Applications**

The reliability of interactions might be uncertain or not fully understood in biological networks such as protein - protein interaction. Researchers study the interaction between proteins in order to better understand living organism's functions, signaling systems and general behaviors. A variety of biological activities depend heavily on interactions between proteins, which frequently cooperate in complex networks. These interactions can include physical bindings and regulatory relationships. The nature and power of these protein-protein interactions, however, are not entirely clear. Due to experimental limitations, environmental variables, or the complexity of biological systems, certain interactions may be widely reported and understood, while others may be unidentified. neutrosophic graph provide a way to represent the uncertainty in protein - protein interaction by assigning T, I and F values to both vertices and edges of the graph. The edge's T value shows "well established interactions", I denote "interactions with some ambiguity", and F defines "interactions that have not been proven yet". Total domination in neutrosophic graphs applied to protein - protein interaction networks aims to identify a subset of proteins that collectively dominate or influence the entire network taking into account the uncertain and varying strength of interactions. Identifying a subset of proteins that collectively dominate the network either directly/ indirectly. This subset should have a significant impact on the overall stability and behavior of the network. When we apply neutrosophic graph for finding the group of proteins the result will be more precise since they are taking into account the interactions with ambiguity which is not present in intuitionistic fuzzy graph.

Below are the benefits of applying total domination in Neutrosophic Graphs for the study of protein - protein interaction

- Identify a group of proteins that collectively play a crucial role in preserving the network's stability and functionality.
- Understand possible therapeutic targets or genetic alterations that might be used to affect the behavior of the entire network.
- Prioritize experimental validation efforts on interactions involving proteins in TD-Set, helping to clarify and refine the understanding of network.

5. Conclusions

The S-VNG, an extension of FG and IFG, increases the system's accuracy, flexibility, and compatibility.
In this research, we suggested a novel idea for identifying the D-Set and TD-Set of a S-VNG using neutrosophic-strong arcs, as well as we defined notions such as neutrosophic-strong arc neighborhood vertices, complete U-SVNG and discussed a few theorems related to total domination in a U-VNG. Furthermore, an application of TD-set in a S-VNG is also discussed. We would like to broaden our research to uncover even more properties on TD-Set in a S-VNG and also want to develop an algorithm for finding the TD-Set of a given S-VNG .

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Conflicts of Interest:

The authors have no conflicts of interest to declare.

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