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γ-Separated sets and γ-Connectedness in L-Fuzzy Topological Spaces

Dapke Sadashiv Ganpatrao
H. J. Thim College of Arts and Science, Mehrun, Jalgaon, India

Abstract
In this paper, we define the γ-connectedness by using of γ-separated sets in L-fuzzy topological spaces. We study the characterization and several properties of γ-connectedness. We have proved some equivalent conditions for γ-connectedness.
***Keywords**: γ-separated sets, γ-closed sets, γ-open sets, γ-connectedness, L-fuzzy topological spaces.*
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Introduction

Let S be the set of all non-negative integers. Connectedness is an important notion in fuzzy topology. In 1975, Bruce Hutton [10] constructed L-fuzzy unit interval $I(L)$ and studied fuzzy topological properties of $I(L)$, where $I = [0,1]$. He proved that if L is ortho-complemented, then fuzzy open sets of $I(L)$ and usual open sets of I are in one-to-one correspondence which preserves unions and interesctions. It follows that $I(L)$ has many fuzzy topological properties such as connectedness. He observed that $I(L)$ does not satisfies connectedness, when L is a chain. Rodabaugh [14] proved that $I(L)$, L-fuzzy open unit interval $(0,1)$(L) and L-fuzzy real line $R(L)$ are connected if $0 \in L^b$ (a condition satisfied by chains), where $L^b = \{\alpha \in L: \alpha < \beta \text{ and } \alpha < \gamma \Rightarrow \alpha < \beta \wedge \gamma\}$. His observation is stated as, A greater degree of connectivity should be associated with a lesser degree of dis-connectivity. Zheng Chong-You [17] studied some properties of L-fuzzy unit interval and defined L-fuzzy path connectedness. He studied the relationship between the different types of fuzzy connectedness such as O-connectedness, Q-connectedness, 1-connectedness and standard L-fuzzy path connectedness.

Ajmal and Kohli [3] introduced the notions of fuzzy connectedness and gave its characterizations. It is observed that fuzzy connectedness is preserved under fuzzy continuity. In [4] he showed that fuzzy C_2-connectedness and fuzzy C_4- connectedness are not preserved under product of spaces. Turanli [16] gives some counter-examples related to the product of fuzzy connected spaces. He coined the term fuzzy super C_s-connectedness and studied it's relations with fuzzy C_s- connectedness.

Liu and Pu [13] introduced the connectedness in fuzzy topological spaces in 1980. G. J. Wang [17] extended the Pu and Liu's definition of connectedness in fuzzy topological spaces to L-fuzzy topological spaces. Many researchers have studied various kinds of connectedness [1], [2], [8] in L-fuzzy topological spaces in the Chang's [6] sense. By using pre-closed sets, Bai [5] introduced P - connectedness and Li et. al. [11] introduced P_2-connectedness in L-fuzzy topological spaces.

Recently, El-Atik [7] studied b-connectedness and their applications in general topology. Hanafy [9] defined the concept of γ-open set and introduced γ- connectedness in fuzzy topological space. He studied some properties of γ-open set and fuzzy γ-continuity in fuzzy topological spaces.

In this paper, we define the γ-connectedness by using of γ-separated sets in L-fuzzy topological spaces. We study the characterization and several properties of γ-connectedness. We have proved some equivalent conditions for γ-connectedness.

Separated Sets in L-Fuzzy Topological Spaces

In this section, we discuss some preliminary terms which are useful for our main results. Liu [12] introduced the concept of separated sets in L-fuzzy topological spaces. Separated sets in L-fuzzy topological spacesare also termed as separated L-fuzzy sets. We some definition given by Liu [12] as follows:

Definition 2.1. [12] Let (X, τ) be an L-fuzzy topological space and $A, B \in L^X$. Then A and B are called separated if $A \wedge cl(B) = 0$and $B \wedge cl(A) = 0$.

Definition 2.2. [12] Let (X, τ) be an L-fuzzy topological space and $A \in L^X$. Then A is said to be connected if A cannot be represented as join of two separated non-null L-fuzzy sets.

Definition 2.3. [9] Let (X, τ) be an L-fuzzy topological space and $A \in L^X$.

Then A is said to be γ-open if

$$A \leq cl(int(A)) \vee int(cl(A))$$

and γ-closed if

$$cl\big(int(A)\big) \vee int\big(cl(A)\big) \leq A.$$

Definition 2.4. [9] Let (X, τ) be an L-fuzzy topological space and $A \in L^X$.

The fuzzy γ-interior of A (in short γ-int(A)) is defined as γ-int(A) $= \bigvee\{H: H\ is\ \gamma - open\ L - fuzzy\ set, H \leq A\}$. The γ-interior of A is the join of all γ-open subsets of L^X contained in A.

The γ-interior of $A \in L^X$ is just largest γ-open subset of L^X contained in A. Note that L-fuzzy set A is γ-open iff γ-int(A) = A.

Definition 2.5. [9] Let (X, τ) be an L-fuzzy topological space and $A \in L^X$.

The fuzzy γ-closure of A (in short γ-cl(A)) is defined as γ-cl(A) $= \bigwedge\{G: G\ is\ \gamma - closed\ L - fuzzy\ set, A \leq G\}$. The γ-closure of A is the meet of all γ-closed subsets of L^X containing A.

The γ-closure of $A \in L^X$ is just smallest γ-closed subset of L^X containing A. Note that L-fuzzy set A is γ-closed iff γ-cl(A) = A.

γ-Separated L-fuzzy Sets in L-Fuzzy Topological Spaces

In this section, We discuss γ −separated L-fuzzy sets in L-fuzzy topological spaces. We proved that every separated sets are γ-separated. We study some characterization and several properties of γ-separated sets.

Definition 3.1.[15]Let (X, τ) be an L-fuzzy topological space and $A, B \in L^X$. Then A, B are called γ-separated if $A \wedge \gamma - cl(B) = 0$ and $B \wedge \gamma - cl(A) = 0$.

Proposition 3.1. [15] Every separated L-fuzzy set in L-fuzzy topological space $(X, \tau)$is γ- separated.

Proof. Let A and B are separated L-fuzzy sets in L-fts (X, τ). By Definition 2.1, we have $A \wedge cl(B) = 0$ and $B \wedge cl(A) = 0$. By using the fact $\gamma - cl(A) \leq cl(A)$ for every $A \in L^X$, we get $A \wedge \gamma - cl(B) = 0$ and $B \wedge \gamma - cl(A) = 0$. Hence by Definition 2.6, A and B are γ-separated L-fuzzy sets in L-fts (X, τ).

Theorem 3.1.[15] Let (X, τ) be L-fuzzy topological space and $A, B \in L^X$ such that

$A \neq 0 \quad and\ B \neq 0$. Then following statements hold;

I. If A and B are γ-separated L-fuzzy sets and A_1, B_1 are non-null L-fuzzy sets in L-fts (X, τ) such that $A_1 \leq A$ and $B_1 \leq B$, then A_1, B_1 are also γ-separated.
II. If $A \wedge B = 0$ such that each of A and B are both γ-closed (γ-open), then A and B are γ-separated.
III. Let A and B be both γ-closed (γ-open). If $H = A \wedge B'$ and $G = B \wedge A'$, then H and G are γ-separated.

Proof:(I) Given $A_1 \leq A$ and $B_1 \leq B$ then $\gamma - \mathrm{cl}(A_1) \leq \gamma - \mathrm{cl}(A)$and $\gamma - \mathrm{cl}(B_1) \leq \gamma - \mathrm{cl}(B)$. Since, A and B are γ-separated L-fuzzy sets, so $A \wedge \gamma - cl(B) = 0$ and $B \wedge \gamma - cl(A) = 0$, then

$$A \wedge \gamma - cl(B) = 0 \text{ and } B \wedge \gamma - cl(A) = 0$$

$$\Rightarrow A_1 \wedge \gamma - cl(B) = 0 \text{ and } B_1 \wedge \gamma - cl(A) = 0$$

$$\Rightarrow A_1 \wedge \gamma - cl(B_1) = 0 \text{ and } B_1 \wedge \gamma - cl(A_1) = 0$$

Hence, A_1, B_1 are also γ-separated.

(II) Since A and B are γ-closed so $A = \gamma - cl(A)$, $B = \gamma - cl(B)$ and $A \wedge B = 0$, then $\gamma - cl(A) \wedge B = 0$, $\gamma - cl(B) \wedge A = 0$. Hence, A and B are γ-separated.

Since A and B are γ-open so A' and B' are γ-closed so $A' = \gamma - cl(A')$, $B' = \gamma - cl(B')$ and $A' \wedge B' = 0$. then $\gamma - cl(A) \wedge B = 0$, $\gamma - cl(B) \wedge A = 0$. Therefore, A' and B' are γ-separated. Clearly,

$A \leq B' \Rightarrow \gamma - cl(A) \leq \gamma - cl(B') \Rightarrow \gamma - cl(A) \leq B' \Rightarrow \gamma - cl(A) \wedge B = 0$.

Similarly, we get $A \wedge \gamma - cl(B) = 0$. Hence, A and B are γ-separated.

(III) If A and B are γ-open L-fuzzy sets then A' and B' are γ-closed L-fuzzy sets so $A' = \gamma - cl(A')$, $B' = \gamma - cl(B')$. Since, $H = A \wedge B'$ and $G = B \wedge A'$ then $H \leq A$ and $G \leq B$, also

$H = A \wedge B'$and $G = B \wedge A'$

$\Rightarrow \gamma - cl(H) \leq \gamma - cl(B') = B'$and $\gamma - cl(G) \leq \gamma - cl(A') = A'$

$\Rightarrow \gamma - cl(H) \wedge B = 0$ and $\gamma - cl(G) \wedge A = 0$

$\Rightarrow \gamma - cl(H) \wedge G = 0$ and $H \wedge \gamma - cl(G) = 0$.

Hence, $G$and H are γ-separated.

If A and B are γ-closed L-fuzzy sets so $A = \gamma - cl(A)$, $B = \gamma - cl(B)$. Since, $H = A \wedge B'$ and $G = B \wedge A'$ then $H \leq B'$and $G \leq A'$, also

$H = A$ and $G = B$

$\Rightarrow \gamma - cl(H) \leq \gamma - cl(A) = A$ and $\gamma - cl(G) \leq \gamma - cl(B) = B$

$\Rightarrow \gamma - cl(H) \wedge A' = 0$ and $\gamma - cl(G) \wedge B' = 0$

$\Rightarrow \gamma - cl(H) \wedge G = 0$ and $H \wedge \gamma - cl(G) = 0$.

Hence, $G$and H are γ-separated.

Theorem 3.2.[15] Let (X, τ) be L-fuzzy topological space and $A, B \in L^X$ such that $A \neq 0$ *and* $B \neq 0$. Then A and B are γ −separated iff there exists γ-open L-fuzzy sets A_1, B_1 in L-fuzzy topological space (X, τ) such that $A \leq A_1, B \leq B_1$ and $A \wedge B_1 = 0$, $A_1 \wedge B = 0$.

Proof. Let$A$ and B are γ −separated L-fuzzy sets in L-fuzzy topological space (X, τ). Take $A_1 = (\gamma - cl(B))^c$ and $B_1 = (\gamma - cl(A))^c$ then A_1 and B_1 are γ-open L-fuzzy sets in L-fuzzy topological space (X, τ) such that $A \leq A_1, B \leq B_1$. We have,

$A_1 = (\gamma - cl(B))^c$and $B_1 = (\gamma - cl(A))^c$

$\Rightarrow A_1 \wedge \gamma\text{-}cl(B) = 0$ and $\gamma\text{-}cl(A) \wedge B_1 = 0$

$\Rightarrow A_1 \wedge B = 0$ and $A \wedge B_1 = 0$.

Hence, $A_1 \wedge B = 0$ and $A \wedge B_1 = 0$.

Conversely, Let A_1, B_1 are γ-open L-fuzzy sets in L-fuzzy topological space (X, τ) such that $A \leq A_1$, $B \leq B_1$ and $A \wedge B_1 = 0$, $A_1 \wedge B = 0$. Then $=B_1 \leq A'$ and $A_1 \leq B'$. Since, A'_1, $B'_1$are γ-closed L-fuzzy sets in L-fuzzy topological space (X, τ) then $\gamma\text{-}cl(A_1') = A_1$ and $\gamma\text{-}cl(B_1{}') = B_1$.

Now,

$$\gamma\text{-}cl(A) \leq \gamma\text{-}cl(A_1) \leq \gamma\text{-}cl(B') = B'$$

and

$$\gamma\text{-}cl(B) \leq \gamma\text{-}cl(B_1) \leq \gamma\text{-}cl(A') = A'.$$

Thus, $\gamma\text{-}cl(A) \wedge B = 0 \; and \; \gamma\text{-}cl(B) \wedge A = 0$.

Hence, $A$and B are γ-separated.

Theorem 3.3.[15] Let (X, τ) be L-fuzzy topological space and $A, B, C \in L^X$. If B and C are γ-separated then $A \wedge B = 0$ and $A \wedge C = 0$ are γ-separated.

Proof. Let (X, τ) be L-fuzzy topological space and $A, B, C \in L^X$. If B and C are γ-separated then $B \wedge \gamma - cl(C) = 0$ and $\gamma - cl(B) \wedge C = 0$. Since, $A \wedge B \leq B$ and $A \wedge C \leq C$ implies $\gamma\text{-}cl(A \wedge B) \leq \gamma\text{-}cl(B)$ and $\gamma\text{-}cl(A \wedge C) \leq \gamma\text{-}cl(C)$.

We get,

$$\gamma\text{-}cl(A \wedge B) \wedge (A \wedge C) \leq \gamma\text{-}cl(B) \wedge C = 0$$

And

$$(A \wedge B) \wedge \gamma\text{-}cl(A \wedge C) \leq B \wedge \gamma\text{-}cl(C) = 0.$$

Hence, $A \wedge B$ and $A \wedge C$ are γ-separated.

γ-Connectedness in L-Fuzzy Topological Spaces

In this section, we define the γ-connectedness by using of γ-separated sets in L-fuzzy topological spaces. We study the characterization and several properties of γ-connectedness. We prove some equivalent conditions for γ-connectedness.

Definition 4.1 Let (X, τ) be L-fuzzy topological space and $A \in L^X$. Then A is said to be γ-connected if A cannot be represented as join of two γ-separated non-null L-fuzzy sets. If $A = 1$ is γ-connected, then (X, τ) said to be γ-connected.

Definition 4.2 Let (X, τ) be L-fuzzy topological space and $A \in L^X$. Then A is said to be γ-disconnected if A is not γ-connected.

Theorem 4.1 Every γ-connected L-fuzzy set in L-fuzzy topological space (X, τ) is connected, but converse need not be true.

Proof. Let $A \in L^X$ be γ-connected in L-fuzzy topological space (X, τ). Sup-pose, A is not connected in (X, τ). Then A can be represented as join of two separated non-null L-fuzzy sets. i.e. $A = B \vee C$ such that $B \neq 0$, $C \neq 0$, $B, C \in L^X$. By Proposition 3.1. We get B, C are γ-separated in (X, τ). So, A can be represented as join of two γ-separated non-null L-fuzzy sets. Thus A is not γ-connected. Which contradicts to our assumption. Hence, every γ-connected L-fuzzy set in L-fuzzy topological space (X, τ) is connected.

To disprove converse, we see following example.

Example 4.1. Let $X = \{x, y\}$, $L = \{0, 1, a, b\}$,

where, $0' = 1$, $1' = 0$, $a' = a$, $b' = b$, $0 < a < 1$, $0 < b < 1$, $a \wedge b = 0$, $a \vee b = 1$,a and b are incomparable.

Define, $A, B, C, D \in L^X$ as

$$A(x) = 1, \quad A(y) = 0,$$

$$B(x) = a, \quad B(y) = b,$$

$$C(x) = a, \quad C(y) = 0,$$

$$D(x) = 0, \quad D(y) = b.$$

Then, $\tau = \{\underline{0}, \underline{1}, \underline{A}\}$ is L-fuzzy topology on X. Thus, (X, τ) is L-fuzzy topological space.

We obtain, $cl(C) = \underline{1}$ and $cl(C) \wedge D = \underline{0}$. Therefore, C and D are not separated. Now, B can only be expressed as join of disjoint non-null L-fuzzy sets C and D. Thus, B is connected L-fuzzy set.

By simple computation, we can see that,

$$int(cl(B)) \wedge cl(int(B)) \leq \underline{1} \wedge \underline{0} = \underline{0} \leq B.$$

$$int(cl(C)) \wedge cl(int(C)) \leq \underline{1} \wedge \underline{0} = \underline{0} \leq C.$$

$$int(cl(D)) \wedge cl(int(D)) \leq \underline{0} \wedge \underline{0} = \underline{0} \leq D.$$

So, B, C, D are γ-closed L-fuzzy sets. Thus, $\gamma\text{-}cl(B) = B$, $\gamma\text{-}cl(C) = C$ and

$\gamma\text{-}cl(D) = D$. Now, $C \wedge \gamma\text{-}cl(D) = C \wedge D = \underline{0}$. Hence, C and D are γ-separated non-null L-fuzzy sets. Since, $B = C \vee D$. Hence, B is γ-disconnected.

Theorem 4.2. Let (X, τ) be an L-fuzzy topological space and $A \in L^X$. Then following conditions are equivalent:

(i) (X, τ) is γ-connected.

(ii) A_1, A_2 are γ-open L-fuzzy sets in $L^X, A_1 \vee A_2 = 1, \quad A_1 \wedge A_2 = 0 \implies 0 \in \{A_1, A_2\}$.

(iii) A_1, A_2 are γ-closed L-fuzzy sets in $L^X, A_1 \vee A_2 = 1, \quad A_1 \wedge A_2 = 0 \implies 0 \in \{A_1, A_2\}$.

Proof. (i) $\Longrightarrow$ (ii) : If (ii) is not true then there exist two non-null γ-open L- fuzzy sets A_1, A_2 such that $A_1 \vee A_2 = 1$ and $A_1 \wedge A_2 = 0$. Since, the compliment of γ-open L-fuzzy set is γ-closed L- fuzzy set. So A_1', A_2' are γ-closed. Clearly, $\gamma\text{-}cl(A_1') = A_1'$ and $\gamma\text{-}cl(A_2') = A_2'$. We have

$\gamma\text{-}cl(A_1') \wedge A_2' = A'_1 \wedge A_2' = 0, \quad A_1' \vee \gamma\text{-}cl(A_2') = A'_1 \vee A_2' = 1$ and

$A_1' \wedge \gamma\text{-}cl(A_2') = A'_1 \wedge A_2' = 0, \quad \gamma\text{-}cl(A_1') \vee A_2' = A'_1 \vee A_2' = 1$. Since, no one of A_1' and A_2' is 0. So, A_1' and A_2' are γ-separated L-fuzzy sets. This implies that (X, τ) is γ-disconnected. Hence, proof.

(ii) $\Longrightarrow$ (iii) : Let A_1, A_2 are γ–open and $A_1 \vee A_2 = 1, A_1 \wedge A_2 = 0 \implies 0 \in \{A_1, A_2\}$. Then $A'_1 \vee A'_2 = 1$, $A'_1 \wedge A'_2 = 0 \implies 0 \in \{A'_1, A'_2\}$. where A_1' and A_2' are γ-closed L-fuzzy sets. Hence, we get (iii).

(iii) $\Longrightarrow$ (i) : If (i)is not true then there exist γ-separated two non-null γ-closed L-fuzzy sets A_1 and A_2 such that $A_1 \vee A_2 = 1$ which says that (iii) is not true. Hence, the proof.

Theorem 4.3. Let (X, τ) be an L-fuzzy topological space and $A \in L^X$. Then following conditions are equivalent:

(i) A is γ-connected.

(ii) $A_1, A_2 \in L^X$ are γ-separated, $A \leq A_1 \vee A_2 \Rightarrow A \leq A_1 \; or \; A \leq A_2$.

(iii) $A_1, A_2 \in L^X$ are γ-separated, $A \leq A_1 \vee A_2 \Rightarrow A \wedge A_1 = 0 \; or \; A \wedge A_2 = 0$.

Proof.(i) $\Longrightarrow$ (iii) : Let A be γ-connected. If $A_1, A_2 \in L^X$ are γ-separated, then by theorem 3.3, $A \wedge A_1$ and $A \wedge A_2$ are γ-separated. Since A is γ-connected, so A cannot be represented as join of two γ-separated non-null L-fuzzy sets. We have $A = A\wedge(A_1 \vee A_2) = (A\wedge A_1)\vee(A \wedge A_2)$ *and* $A \leq A_1\vee A_2$, which implies that $A\wedge A_1 = 0$ or $A\wedge A_2 = 0$. Hence, we get (iii).

(iii) ⟹ (ii) : Let A_1, A_2 are γ-separated L-fuzzy sets in (X,τ) such that $A \leq A_1 \vee A_2$. Then $A\wedge A_1 = 0$ *or* $A \wedge A_2 = 0$. Suppose, $A\wedge A_1 = 0$, then $A = A\wedge(A_1 \vee A_2) = (A\wedge A_1)\vee(A \wedge A_2) = 0\vee(A \wedge A_2) = (A \wedge A_2) \Rightarrow A \leq A_2$.

Similarly, suppose, $A\wedge A_2 = 0$, then $A = A\wedge(A_1 \vee A_2) = (A\wedge A_1)\vee(A \wedge A_2) = (A\wedge A_1)\vee 0 = (A \wedge A_1) \Rightarrow A \leq A_1$.

Hence, we get (ii).

(ii) ⟹ (i) : Let$A_1, A_2 \in L^X$ are γ-separated and $A \leq A_1\vee A_2$. Then $A \leq A_1$or $A \leq A_2$. Since, A_1andA_2 are γ-separated, so $A_1\wedge\gamma\text{-}cl(A_2) = 0$ and $\gamma\text{-}cl(A_1)\wedge A_2 = 0$. If $A \leq A_1$, then $A_2 = (A_2\wedge A) \leq (A_2\wedge A_1) \leq (A_2 \wedge\gamma\text{-}cl(A_1))$=0. If $A \leq A_2$, then $A_1 = (A_1\wedge A) \leq (A_1\wedge A_2) \leq (A_1 \wedge\gamma\text{-}cl(A_2))$=0. So A can not be represented as join of two γ-separated non-null L-fuzzy sets. Thus, A is γ-connected. Hence, we get (i).

Theorem 4.4. Let (X, τ) be an L-fuzzy topological space. Then following statements are equivalent:

(a) (X, τ) is γ-disconnected.

(b) There exist two non-null γ-closed L-fuzzy sets A and B in L^X such that $A\vee B = 1$ and $A\wedge B = 0$.

(c) There exist two non-null γ-open L-fuzzy sets A and B in L^X such that $A \vee B = 1$ and $A\wedge B = 0$.

Proof. This is an immediate consequence of Theorem 4.2.

Theorem 4.5. Let (X, τ) be an L-fuzzy topological space and $A \in L^X$. If A is γ-connected then γ-cl(A) is γ-connected.

Proof. Suppose that γ-$cl(A)$ is γ-disconnected then there are two non-null γ-separated L-fuzzy sets G and H in L^X such that $\gamma\text{-}cl(A) = G\vee H$. We have, $A = (G\wedge A)\vee(H\wedge A)$ and $\gamma\text{-}cl(G\wedge A) \leq \gamma\text{-}cl(G), \gamma\text{-}cl(H\wedge A) \leq \gamma\text{-}cl(H)$. Since, G and H are γ-separated, so

$$\gamma\text{-}cl(G)\wedge H = 0 \text{ and } G\wedge \gamma\text{-}cl(H) = 0$$

$$\gamma\text{-}cl(G\wedge A)\wedge H = 0 \text{ and } G\wedge \gamma\text{-}cl(H\wedge A) = 0$$

$$\gamma\text{-}cl(G\wedge A)\wedge(H\wedge A) = 0 \text{ and } (G\wedge A)\wedge \gamma\text{-}cl(H\wedge A) = 0.$$

Therefore, A is γ-disconnected. It is contradiction to assumption. Hence, γ-$cl(A)$ is γ-connected.

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