Fuzzy $\gamma$-Hyper Connectedness in Fuzzy Topological Spaces

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Abstract. In this paper we introduce the concept of fuzzy $\gamma$-hyper connected space with the help of fuzzy $\gamma$-connected sets. Some basic theorems and results of these spaces are also discussed.

Keywords: Fuzzy $\gamma$-open set; Fuzzy $\gamma$-connected; fuzzy P-space; fuzzy Baire space; fuzzy hyper connected spaces.

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1. Introduction

The concept of fuzzy sets which formed the backbone of fuzzy mathematics was first introduced by Zadeh [20] in his classical paper in the year of 1965. The theory of fuzzy topological spaces was introduced and developed by Chang [4] in 1968. Since then much attention has been imply to develop and generalize the fundamental concepts of general topology in fuzzy setting by many authors. Thus a modern theory of fuzzy topology has been developed. In recent fuzzy topology has been found to be very useful in solving many industrial problems. In 2000, [9] Naschie showed that notion of fuzzy topology be relevant to Quantum particle physics.

The concept of fuzzy $\gamma$-open set was introduced by Hanfy et al. [8] in 1999 as a union of notation of fuzzy semi-open sets and fuzzy preopen sets. Hanafy introduced the fuzzy $\gamma$-open sets which are weaker than each of them. Using this notation, he studied fuzzy $\gamma$-continuous mapping on fuzzy topological space. In 2015, Thangaraj et al. [12] discussed fuzzy hyper-connected in fuzzy topological space and studied its properties.

We introduce and study the concepts of fuzzy $\gamma$-hyper connectedness by using fuzzy $\gamma$-connected sets in fuzzy topological space. Several characterizations of fuzzy $\gamma$-hyper connectedness in fts in terms of fuzzy $G_{\alpha}$ sets, fuzzy $\gamma$-first category sets and fuzzy $\gamma$-no where dense sets are also established in this paper. Also we discuss some theorems and results on this spaces.

2. Preliminaries

Some basic definitions and properties which will be needed are recalled in this section. In this paper we use the notion of a fuzzy topology in the original sense of Chang (1968). Throughout this paper by $(X,\tau)$ we mean a fuzzy topological space (fts, shortly).
For a fuzzy set $\lambda$ in a fts $(X, \tau)$, $\text{cl} \lambda$, $\text{int} \lambda$, $\text{intcl} \lambda$ will respectively stand for the fuzzy closure, fuzzy interior and interior closure interior of $\lambda$ in $(X, \tau)$.

**Definition 2.1.** [8] A fuzzy subset $\lambda$ of fuzzy topological space $(X, \tau)$ is said to be fuzzy-$\gamma$ open set (res. fuzzy-$\gamma$ closed set) if

$$\lambda \leq \text{cl}\text{int} \lambda \lor \text{intcl} \lambda \quad (\text{res. } \lambda \geq \text{cl}\text{int} \lambda \land \text{intcl} \lambda)$$

Also, it may be write that the complement of fuzzy-$\gamma$-open set is fuzzy-$\gamma$-closed set. Any union (resp. intersection) of fuzzy-$\gamma$-open (resp. fuzzy-$\gamma$-closed) set is fuzzy-$\gamma$-open (resp. fuzzy-$\gamma$-closed). But intersection of two fuzzy-$\gamma$ open sets need not be fuzzy-$\gamma$ open. The intersection of a fuzzy open set which is a crisp subset and a fuzzy-$\gamma$ open set is fuzzy-$\gamma$ open. The union of fuzzy closed set which is a crisp subset and fuzzy-$\gamma$ closed set is fuzzy-$\gamma$ closed.

**Remark 2.2.** It is obvious that every fuzzy open (resp. fuzzy closed) set is a fuzzy-$\gamma$-open set (resp. fuzzy-$\gamma$-closed set). But the converse need not be true in general.

It is also clear that a fuzzy-$\gamma$ open set is weaker than the concepts of fuzzy semi open or fuzzy pre open set and stronger than concepts of fuzzy semi open set.

**Proposition 2.3.** [1] If $\mu$ and $\lambda$ are two fuzzy subsets of a fts $(X, \tau)$ then

(i) $\text{cl} \mu \lor \text{cl} \lambda = \text{cl}(\mu \lor \lambda)$ and $\text{cl} \mu \land \text{cl} \lambda \supseteq \text{cl}(\mu \land \lambda)$

(ii) $\text{int} \mu \land \text{int} \lambda = \text{int}(\mu \land \lambda)$ and $\text{int} \mu \lor \text{int} \lambda \subseteq \text{int}(\mu \lor \lambda)$

(iii) $1 - \text{int} \lambda = \text{cl}(1 - \lambda)$

(iv) $1 - \text{cl} \lambda = \text{int}(1 - \lambda)$.

**Definition 2.4.** [8] The $\gamma$-interior and $\gamma$-closure of a fuzzy set $A$ in $(X, \tau)$ are denoted by $\gamma\text{-int}(A)$ and $\gamma\text{-cl}(A)$ respectively and are defined as

$$\gamma\text{-int}(A) = \lor \{B: B \leq A, B \text{ is fuzzy } \gamma\text{-open set in } X\}$$

$$\gamma\text{-cl}(A) = \land \{C: C \geq A, C \text{ is fuzzy } \gamma\text{-closed set in } X\}.$$  

Here, let $\mu_A(x)$ and $\mu_B(x)$ be the membership function of every $x$ in $A$ and $B$ respectively. Then a member of $A$ is contained in a member of $B$ which is denoted by $A \leq B$ iff $\mu_A(x) \leq \mu_B(x)$.

**Proposition 2.5.** [8] If $\lambda$ is a subset of $(X, \tau)$ and $\lambda'$ is its complement then

(i) $\gamma\text{-cl}\lambda' = (\gamma\text{-int}\lambda)'$

(ii) $\gamma\text{-int}\lambda' = (\gamma\text{-cl}\lambda)'$.

**Theorem 2.6.** [8] i) Each fuzzy semi pre open set which is fuzzy closed is fuzzy-$\gamma$-open.

ii) Each fuzzy-$\gamma$-open set which is fuzzy closed is fuzzy semi open.

**Definition 2.7.** [11] i) A fuzzy set $\lambda$ in a fuzzy topological space $(X, \tau)$ is called fuzzy dense if there exists no fuzzy closed set $\mu$ in $(X, \tau)$ such that $\lambda \prec \mu$<1. That is, $\text{cl}(\lambda)=1$.

(ii) A fuzzy set $\lambda$ in a fts $(X, \tau)$ is called fuzzy nowhere dense if there exists no non-zero fuzzy open set $\mu$ in $(X, \tau)$ such that $\mu < \text{cl}(\lambda)$, that is $\text{intcl}(\lambda)=0$.  

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Definition 2.8. [3] A fuzzy set $\lambda$ in a fts $(X, \tau)$ is called a fuzzy $G_\delta$-set in $(X, \tau)$ if $\lambda = \bigwedge_{i=1}^\infty (\lambda_i)$ where $\lambda_i \in \tau$ for $i \in \Lambda$.

Proposition 2.9. [1] For a family $A$ of $\{\lambda_\alpha\}$ of fuzzy sets of a fts $(X, \tau)$, $\forall \text{cl}(\lambda_\alpha) \leq \text{cl}(\lambda_\alpha)$. In case $A$ is finite set, $\forall \text{cl}(\lambda_\alpha) = \text{cl}(\lambda_\alpha)$.

Also $\forall \text{int}(\lambda_\alpha) \leq \text{int}(\lambda_\alpha)$ in $(X, \tau)$.

Definition 2.10. [113] A fts $(X, \tau)$ is called a fuzzy Baire space if $\forall \text{int}(\bigwedge_{i=1}^\infty (\lambda_i)) = 0$, where $(\lambda_i)$'s are fuzzy nowhere dense sets in $(X, \tau)$.

Definition 2.11. [13] A fuzzy set $\lambda$ in fts $(X, \tau)$ is called a fuzzy first category set if $\forall \lambda = \bigvee_{i=1}^\infty (\lambda_i)$, where $(\lambda_i)$'s are nowhere dense sets in $(X, \tau)$. Any other fuzzy set in $(X, \tau)$ is said to be of fuzzy second category.

Definition 2.12. [11] A fts $(X, \tau)$ is called a fuzzy first category set if $\forall \lambda = \bigvee_{i=1}^\infty (\lambda_i) = 1$, where $(\lambda_i)$'s are nowhere dense sets in $(X, \tau)$. Any other fts $(X, \tau)$ is said to be of fuzzy second category.

Theorem 2.13. [13] If $\lambda$ is a fuzzy dense set and fuzzy $G_\delta$ set in a fuzzy topological space $(X, \tau)$, then $1-\lambda$ is a fuzzy first category set in $(X, \tau)$.

Definition 2.14. [10] A fts $(X, \tau)$ is called fuzzy P-space if every non zero fuzzy $G_\delta$-set in $(X, \tau)$ is fuzzy open in $(X, \tau)$. That is, if $\lambda = \bigwedge_{i=1}^\infty (\lambda_i)$ where $\lambda_i \in \tau$ for $i \in \Lambda$.

Definition 2.15. [16] A fts $(X, \tau)$ is called a fuzzy Volterra space if $\forall \lambda = \bigwedge_{i=1}^\infty (\lambda_i)$, where $(\lambda_i)$'s are fuzzy dense and fuzzy $G_\delta$-sets in $(X, \tau)$.

Definition 2.16. [5] A fuzzy topological space $X$ is said to be fuzzy hyper connected if every non null fuzzy open subset of $X$ is fuzzy dense in $X$. That is, a fuzzy topological space $(X, \tau)$ is fuzzy hyper connected if $\forall \lambda = \text{cl}(\lambda) = 1$, for all $\lambda \in \tau$.

3. Fuzzy $\gamma$-hyper connected space

Definition 3.1. A fuzzy topological space $X$ is called fuzzy $\gamma$-connected if there is no proper fuzzy set of $X$, which is both fuzzy $\gamma$-open and fuzzy $\gamma$-closed.

Definition 3.2. A fuzzy topological space $(X, \tau)$ is called fuzzy $\gamma$-hyper connected if every non null fuzzy $\gamma$-open subset of $X$ is fuzzy dense set. That is, a fts $(X, \tau)$ is fuzzy $\gamma$-hyper connected if for every non null fuzzy $\gamma$-open subset $\mu$ of $X$, $\text{cl}(\mu) = 1$.

Proposition 3.3. A fuzzy topological space $(X, \tau)$ is fuzzy $\gamma$-hyper connected for every non null fuzzy $\gamma$-open subset $\lambda$ of $X$, if $\text{cl}(\lambda) \vee \text{cl}(\lambda) \leq 1$.

Proof. Let $\lambda$ be a fuzzy subset of $(X, \tau)$. For every non null fuzzy $\gamma$-open subset $\lambda$.

$\Lambda \leq \text{cl}(\lambda) \vee \text{int}(\lambda)$

Since $\lambda$ is $\gamma$-hyper connected in $(X, \tau)$

$\therefore \text{cl}(\lambda) = 1$

$\text{cl}(\lambda) \leq \text{cl}(\text{int}(\lambda) \vee \text{int}(\lambda))$
Example 3.6. Let \( \lambda \) be a fuzzy open set, \( \text{cl}(\text{cl}(\lambda)) \geq \text{cl}(\lambda) \) \( \lambda \) is finite fuzzy open set, \( \text{cl}(\lambda) \geq \text{cl}(\lambda) \) \( \Rightarrow \text{cl}(\lambda) \leq \lambda \leq 1 \).

Proposition 3.4. A fts \((X,\tau)\) is fuzzy \( \gamma \)-hyper connected for non null finite fuzzy \( \gamma \)-closed subsets \( \mu \) of \( X \) if \( \text{cl}(\mu) \cap \text{cl}(\mu) \leq 1 \).

Proof: Let \( \mu \) be fuzzy \( \gamma \)-closed set.

Then by definition we have \( \mu \geq \text{cl}(\mu) \cap \text{cl}(\mu) \)

\( 1-\mu \leq 1-\text{cl}(\mu) \cap \text{cl}(\mu) \)

\( \Rightarrow 1-\mu \leq 1-\text{cl}(\mu) \cap \text{cl}(\mu) \)

since \( \mu \) is \( \gamma \)-hyper connected, \( \text{cl}(\mu) \leq 1 \) and \( \text{cl}(\bigvee \mu_i) \leq \text{cl}(\bigvee \mu_i) \)

\( \therefore 1-\mu \leq 1-\text{cl}(\mu) \cap \text{cl}(\mu) \)

\( \Rightarrow 0 \leq 1-\text{cl}(\mu) \cap \text{cl}(\mu) \)

\( \Rightarrow \text{cl}(\mu) \cap \text{cl}(\mu) \leq 1 \)

Theorem 3.5. Arbitrary union of fuzzy \( \gamma \)-hyper connected subset of \( X \) is fuzzy \( \gamma \)-hyper connected set.

Proof: Let \( \{\lambda_i : i \in \Lambda\} \) be collection of fuzzy \( \gamma \)-hyper connected sets of \( X \).

Then, for each \( i \in \Lambda \), we have \( \lambda_i \)

\( \lambda_i \leq \text{cl}(\lambda_i) \cap \text{cl}(\lambda_i) \)

\( \Rightarrow \bigvee \lambda_i \leq \text{cl}(\bigvee \lambda_i) \cap \text{cl}(\bigvee \lambda_i) \)

\( = \text{cl}(\bigvee \lambda_i) \cap \text{cl}(\bigvee \lambda_i) \) \[\text{since } \text{cl}(\lambda_i) \leq \text{cl}(\lambda_i) \]

Taking closure:

\( \text{cl}(\bigvee \lambda_i) \leq \text{cl}(\text{cl}(\bigvee \lambda_i) \cap \text{cl}(\bigvee \lambda_i)) \)

\( = \text{cl}(\bigvee \lambda_i) \cap \text{cl}(\bigvee \lambda_i) \) \[\text{inequality holds in respect of closure property}\]

\( \Rightarrow \text{cl}(\bigvee \lambda_i) \cap \text{cl}(\bigvee \lambda_i) = 1 \).

Imply that \( \bigvee \lambda_i \) is a fuzzy \( \gamma \)-hyper connected in \( \text{fts}(X,\tau) \).

Example 3.6. Let \( \mu_1, \mu_2, \mu_3 \) be fuzzy sets on \( X = [0,1] \) defined as

\[\mu_1(x) = 0 \quad \text{if} \quad 0 \leq x \leq \frac{1}{2} \quad \mu_2(x) = 1 \quad \text{if} \quad 0 \leq x \leq \frac{1}{4} \quad \mu_3(x) = 0 \quad \text{if} \quad 0 \leq x \leq \frac{1}{4} \]

\[= 2x - 1 \quad \text{if} \quad \frac{1}{2} \leq x \leq 1 \quad = -4x + 2 \quad \frac{1}{4} \leq x \leq \frac{1}{2} \quad = \frac{4x - 1}{3} \quad \frac{1}{4} \leq x \leq 1 \quad = 0 \quad \frac{1}{2} \leq x \leq 1\]

Consider \( \tau = \{0,1, \mu_1, \mu_2, \mu_3, \mu_1 \vee \mu_2 \} \) on \( X \). In \( (X,\tau) \) \( \mu_2, \mu_3 \) and \( \mu_1 \land \mu_2 \) are fuzzy \( \gamma \)-open sets but \( \mu_1 \land \mu_3 \) is not fuzzy \( \gamma \)-open set.

Indeed \( \mu_2 \land \mu_3 \notin \text{cl}(\mu_2 \land \mu_3) \cap \text{cl}(\mu_2 \land \mu_3) \),

But \( \mu_1 \land \mu_2 \leq \text{cl}(\mu_2 \land \mu_1) \cap \text{cl}(\mu_2 \land \mu_1) \) \[\because \mu_1 \land \mu_2 \text{ is fuzzy } \gamma \text{-open set and } \text{cl}(\mu_2 \land \mu_1) = 0 \]

so, \( \mu_1 \land \mu_2 \) is not fuzzy \( \gamma \)-hyper connected set in \( (X,\tau) \).

But \( \mu_2, \mu_3 \) are fuzzy \( \gamma \)-open set.

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And also $\text{cl}\mu_2 = 1$, $\text{cl}\mu_3 = 1$.
Therefore, $\mu_2, \mu_3$ are fuzzy $\gamma$-hyper connected sets.

**Definition 3.7.** A fuzzy $\gamma$-open set $\lambda$ in fts $(X, \tau)$ is called fuzzy $\gamma$ dense if there exists no fuzzy $\gamma$-closed set $\mu$ in $(X, \tau)$ such that $\lambda < \mu < 1$; That is $\text{cl}(\lambda) = 1$.

**Definition 3.8.** A fuzzy $\gamma$-open set $\lambda$ in fts $(X, \tau)$ is said fuzzy nowhere $\gamma$-dense if there exists no non zero $\gamma$-open set $\mu$ in $(X, \tau)$ such that $\mu < \text{cl}(\lambda)$. That is, $\text{int}\text{cl}(\lambda) = 0$.

**Definition 3.9.** A fuzzy $\gamma$-open set $\lambda$ in fts $(X, \tau)$ is called fuzzy $\gamma$- $F_\sigma$-set in $(X, \tau)$ if
$$\lambda = \bigvee_{i=1}^{\propto} (\lambda_i),$$
where $\lambda_i \in \tau$ for $i \in I$.

**Definition 3.10.** A fuzzy $\gamma$-open set $\lambda$ in fts $(X, \tau)$ is called fuzzy $\gamma$- $G_\delta$-set in $(X, \tau)$ if
$$\lambda = \bigwedge_{i=1}^{\propto} (\lambda_i),$$
where $\lambda_i \in \tau$ for $i \in I$.

**Definition 3.11.** A fts $(X, \tau)$ is called a fuzzy $\gamma$-Baire space if $\text{int}(\bigvee_{i=1}^{\propto} (\lambda_i)) = 0$, where $(\lambda_i)$'s are fuzzy nowhere dense sets in $(X, \tau)$.

**Definition 3.12.** A fuzzy $\gamma$-open set $\lambda$ in a fts $(X, \tau)$ is fuzzy first category $\gamma$ set if
$$\lambda = \bigvee_{i=1}^{\propto} (\lambda_i),$$
where $(\lambda_i)$'s are fuzzy nowhere $\gamma$-dense sets in $(X, \tau)$. Any other fuzzy $\gamma$ set in $(X, \tau)$ is said to be fuzzy second category.

**Definition 3.13.** A fts $(X, \tau)$ is called $\gamma$-P space if countable intersection of fuzzy $\gamma$-open sets in $(X, \tau)$ is fuzzy $\gamma$-open space. That is, every non zero fuzzy $\gamma$-$G_\delta$-set in $(X, \tau)$ is fuzzy $\gamma$-open in $(X, \tau)$.

**Theorem 3.14.** If a fuzzy $\gamma$-P space $(X, \tau)$ is a fuzzy $\gamma$-hyper connected space, then $(X, \tau)$ is a fuzzy $\gamma$-Baire space.

**Proof:** Here, let $\lambda$ be a fuzzy $\gamma$- $G_\delta$ space in fuzzy $\gamma$-P space $(X, \tau)$.
Since, fts $(X, \tau)$ is fuzzy $\gamma$-hyper connected space, the fuzzy $\gamma$-open set $\lambda$ is dense set in $(X, \tau)$ i.e. $\text{Cl}(\lambda) = 1$.

Also, we know, since $\lambda$ is fuzzy $\gamma$-P space and $\gamma$-dense set, Therefore, $(1-\lambda)$ is first category set in $(X, \tau)$.
$$\therefore (1-\lambda) = \bigvee_{i=1}^{\propto} (\lambda_i),$$
where $(\lambda_i)$'s are fuzzy nowhere dense sets in $(X, \tau)$

Since $\text{int}(\bigvee_{i=1}^{\propto} (\lambda_i)) = 0$. Where $\lambda_i$ are fuzzy nowhere dense set, $\Rightarrow (X, \tau)$ is fuzzy $\gamma$-Baire space.

**Theorem 3.15.** If a fuzzy $\gamma$-P space $(X, \tau)$ is a fuzzy $\gamma$-hyper connected space, then $(X, \tau)$ is a fuzzy $\gamma$-second category space.

**Proof:** Let the fuzzy $\gamma$-P space $(X, \tau)$ be a fuzzy $\gamma$-hyper connected space. By above theorem, it may write that $(X, \tau)$ is fuzzy $\gamma$-Baire space.
$$\therefore \text{Int}(\bigvee_{i=1}^{\propto} (\lambda_i)) = 0$$
Where $(\lambda_i)$'s are no where dense sets in $(X, \tau)$
We have to show that $\bigvee_{i=1}^{\propto} (\lambda_i) \neq 1$. Suppose $\bigvee_{i=1}^{\propto} (\lambda_i) = 1$
This imply that
\[ \text{Int}[\bigvee_{i=1}^{\infty} (\lambda_i)] = \text{int}[1] = 1 \neq 0, \text{ a contradiction.} \]

Hence we must have \( \bigvee_{i=1}^{\infty} (\lambda_i) \neq 1 \), where \( (\lambda_i) \) are fuzzy \( \gamma \)-nowhere dense set in \((X,\tau)\).

Therefore \((X,\tau)\) is fuzzy \( \gamma \)-second category space.

**Definition 3.16.** A fuzzy topological space \((X,\tau)\) is called a fuzzy \( \gamma \)-Volterra space if \( \text{cl}(\bigwedge_{i=1}^{k} (\lambda_i)) = 1 \), where \( (\lambda_i) \) are fuzzy \( \gamma \)-dense and fuzzy \( \gamma \)-\( G_\delta \) sets in \((X,\tau)\). Otherwise, its \((X,\tau)\) is fuzzy \( \gamma \)-Volterra space if \( \text{cl}(\bigwedge_{i=1}^{k} (\lambda_i)) = 1 \), where \( (\lambda_i) \) are fuzzy dense and \( G_\delta \) set in \((X,\tau)\).

**Theorem 3.17.** If there are \( k \) fuzzy \( \gamma \)-\( G_\delta \) sets, \( (\lambda_i) \)'s \((i = 1 \text{ to } k)\) in fuzzy \( \gamma \)-hyper connected and fuzzy \( \gamma \)-P space \((X,\tau)\), then \((X,\tau)\) is a fuzzy \( \gamma \)-Volterra space.

**Proof:** \( (\lambda_i) \) are \( G_\delta \)-sets in a fuzzy \( \gamma \)-hyper connected and fuzzy \( \gamma \)-P space \((X,\tau)\).

Since \((X,\tau)\) is fuzzy \( \gamma \)-P-space, then \( \bigwedge_{i=1}^{k} (\lambda_i) = \lambda \), is also a fuzzy \( \gamma \)-open set.

Since the fuzzy space \((X,\tau)\) is a fuzzy hyper connected space, the fuzzy open set \( \lambda \) in \((X,\tau)\) is a fuzzy dense set. That is, \( \text{cl}\lambda = 1 \)

Hence \( \lambda \) is a fuzzy \( G_\delta \) set and a fuzzy dense set in \((X,\tau)\).

Therefore, \((1-\lambda)\) is 1st category in \((X,\tau)\).

\[ : (1-\lambda) = \bigvee_{i=1}^{\infty} (\lambda_i) \ , \ \lambda_i \text{ is nowhere dense set in } X. \]

Then \( \text{int}(\bigvee_{i=1}^{\infty} (\lambda_i)) = \text{int}(1-\lambda) = 1 - \text{cl}\lambda = 1 - 1 = 0. \)

Therefore, \((X,\tau)\) is a fuzzy \( \gamma \)-Volterra space.

**4. Conclusion**

In this paper, we introduce and study a new concept fuzzy \( \gamma \)-hyper-connectedness in fuzzy topological spaces. The notion of fuzzy open sets are fundamental structure of fuzzy topology. Fuzzy \( \gamma \)-open sets form a link between pre open sets and semi pre-open sets.

This work may be extended to fuzzy strongly \( \gamma \)-connectedness and totally fuzzy \( \gamma \)-disconnectedness with the concepts of fuzzy hyper \( \gamma \)-connectedness spaces. The fuzzy \( \gamma \)-hyper-connectedness may play an important role in computation of fuzzy topology and may have applications in quantum particle physics and quantum gravity, particularly in connection with string theory.

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