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Original Article

On fuzzy *b*-locally open sets in bitopological spaces

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Abstract

In this article we introduce the notion of fuzzy *b*-locally open (*bLO*) sets, fuzzy bLO^* sets, fuzzy bLO^{**} sets in fuzzy bitopological spaces and obtain several characterizations and some properties of these sets. Also we introduce the notion of fuzzy b-locally continuous functions on bitopological spaces.

Keywords: fuzzy bitopological spaces, fuzzy *bLO* sets, fuzzy bLO^* sets, fuzzy bLO^{**} sets.

1. Introduction and Preliminaries

The notion of fuzzy sets was intoduced by L.A. Zadeh in 1965, and thereafter the paper of Chang (1968) paved the way for the subsequent tremendous growth of the numerous fuzzy topological concepts. The notion of fuzzyness has been applied for studying different aspects of mathematics by Tripathy and Baruah (2010); Tripathy and Borgohain (2011); Tripathy *et al.* (2013); Tripathy and Ray (2012); Tripathy and Sarma (2012a) and many workers on sequence spaces in recent years. The notion of bitopological spaces has been investigated from different aspects by Tripathy and Acharjee (2014); Tripathy and Debnath (2013); Tripathy and Sarma (2011; 2012; 2013; 2014) and others. Kandil (1989 introduced the concept of fuzzy bitopological spaces. Later on several authors were attracted by the notion of fuzzy bitopological spaces. The notion of *b*-locally open sets in bitopological spaces was introduced by Tripathy and Sarma (2011). In this paper we introduce the concept of *b*-locally open sets in fuzzy bitopological spaces.

Let (X,τ) be a topological space. Then

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Definition 1.1 [Andrijevic (1996)].

Let $A \subset X$, then A is said to be *b*-open if $A \subset cl(intA) \cap int(clA)$, where $cl(A)$ and $int(A)$ denote the closure and interior of the set A.

Definition 1.2 [Kuratowski and Sierpinski (1921)].

Let $A \subset X$, then A is said to be locally closed if $A = G \cap F$, where G is an open set in X and F is closed in X.

Definition 1.3 [Nasef (2001)].

Let $A \subset X$, then A is said to be *b*-locally closed if $A = G \cap F$, where G is b-open set in X and F is *b*-closed in X.

Definition 1.4 [Tripathy and Sarma (2011)].

A subset A of a bitopological space (X,τ_1,τ_2) is called (τ_1,τ_2)-locally open (in short (τ_1,τ_2)-LO) if $A = G \cup F$, where G is τ_1-closed and F is τ_2-open in (X,τ_1,τ_2).

Definition 1.5 [Tripathy and Sarma (2011)].

A subset A of a space (X,τ_1,τ_2) is called (τ_1,τ_2)- b-locally open(in short (τ_1,τ_2)- bLO) if $A = G \cup F$, where G is τ_1-*b*-closed and F is -*b*-open in (X,τ_1,τ_2).

Definition 1.6 [Tripathy and Sarma (2011)].

A subset A of a space (X,τ_1,τ_2) is called (τ_1,τ_2)-bLO^* if there exists a τ_1-b-closed set G and a τ_2-open set F of

(X, τ_1, τ_2) s.t. $A=G \cup F$.

Definition 1.7 [Tripathy and Sarma (2011)].

A subset A of a space (X, τ_1, τ_2) is called (τ_1, τ_2)-bLO^{**} if there exists a τ_1-closed set G and a τ_2- b-open set F of (X, τ_1, τ_2) s.t. $A=G \cup F$.

Let X be a non-empty set and I, the unit interval [0,1]. A fuzzy set A in X is characterized by a function $\mu_A : X \to I$ where μ_A is called the membership function of A, and throughout we denote fuzzy elements by x_p, p representing the membership grade of x.

The fuzzy operations $\wedge$ and V on the fuzzy sets of X are defined as follows.

Let $A = \{x_p$: for all $x \in X$ and p is the membership of $x \in X\}$
and $B = \{x_q$: for all $x \in X$ and q is the membership of $x \in X\}$
$A \wedge B = \{x_r : x \in X$ and $r = \min\{p, q\}$ for each $x \in X\}$.
and $A \vee B = \{x_r : x \in X$ and $r = \max\{p, q\}$ for each $x \in X\}$.

2. b-locally open sets in fuzzy bitopological spaces

Definition 2.1

A fuzzy set a of a fuzzy bitopological space (X, τ_1, τ_2) is called (τ_1, τ_2)-fuzzy locally open (in short (τ_1, τ_2)-FLO) if $\alpha = \beta \vee \gamma$, where β is τ_1-fuzzy closed and g is τ_2-fuzzy open in (X, τ_1, τ_2).

Definition 2.2

A fuzzy set α of a fuzzy bitopological space (X, τ_1, τ_2) is called (τ_1, τ_2)-fuzzy b-locally open (in short (τ_1, τ_2)-$FbLO$) if $\alpha = \beta \vee \gamma$, where β is τ_1-fuzzy b-closed and γ is t_2-fuzzy b-open in (X, τ_1, τ_2).

Definition 2.3

A fuzzy set α of a fuzzy bitopological space (X, τ_1, τ_2) is called (τ_1, τ_2)- $FbLO^*$ if there exist a τ_1-fuzzy b-closed set β and a τ_2-fuzzy open set g of (X, τ_1, τ_2) such that $\alpha = \beta \vee \gamma$.

Definition 2.4

A fuzzy set a of a fuzzy bitopological space (X, τ_1, τ_2) is called (τ_1, τ_2)- $FbLO^{**}$ if there exist a τ_1-fuzzy closed set β and a τ_2-fuzzy b-open set γ of (X, τ_1, τ_2) such that $\alpha = \beta \vee \gamma$.

Theorem 2.5

Let α be a fuzzy set of (X, τ_1, τ_2). Then if $a \in (\tau_1, \tau_2)$-$FLO(X)$, then

(a) $\alpha \in (\tau_1, \tau_2)$-$FbLO^*(X)$.

(b) $\alpha \in (\tau_1, \tau_2)$-$FbLO^{**}(X)$.

Proof:

(a) Since $\alpha \in (\tau_1, \tau_2)$-$FLO(X)$, so there exists a τ_1-fuzzy closed set β and a τ_2-fuzzy open set γ such that $\alpha=\beta \vee \gamma$.

Since β is τ_1-fuzzy closed, we have int (cl (β)) $\leq \beta$ and cl (int (β)) $\leq \beta$

Therefore, int (cl (β))$\wedge$cl (int (β)) $\leq \beta$.

Hence β is τ_1-fuzzy b-closed.

Thus we have, $\alpha=\beta \vee \gamma$, where β is τ_1 fuzzy b-closed and γ is τ_2-fuzzy open.

Hence $\alpha \in (\tau_1, \tau_2)$-$FbLO^*(X)$.

(b) Since $\alpha \in (\tau_1, \tau_2)$-$FLO(X)$, so there exists a τ_1-fuzzy closed set β and a τ_2-fuzzy open set γ such that $\alpha=\beta \vee \gamma$.

Since γ is τ_2-fuzzy open, we have $\gamma \leq$ int (cl (γ)) and $\gamma \leq$ cl (int (γ))

Therefore, $\gamma \leq$ cl (int (γ))$\vee$int (cl (γ)).

Hence γ is τ_2-fuzzy b-open.

Now, we have, $\alpha=\beta \vee \gamma$, where β is τ_1-fuzzy closed and γ is τ_2-fuzzy b-open.

Hence $\alpha \in (\tau_1, \tau_2)$-$FbLO^{**}(X)$.

Remark 2.6

The converse is not necessarily true. It is clear from the following example:

Example 2.7

Let $X = \{a, b, c\}$ and consider the fuzzy sets on X are $\alpha_1 = \{a_{0.3}, b_{0.8}, c_0\}$, $\alpha_2 = \{a_{0.4}, b_{0.4}, c_0\}$ and $\alpha = \{a_{0.4}, b_{0.5}, c_0\}$. Let $\tau_1 = \{\underline{0}, \underline{1}, \alpha_1, \alpha_2, \alpha_1 \vee \alpha_2, \alpha_1 \vee \alpha_2\}$ and $\tau_2 = \{\underline{0}, \underline{1}, \alpha_1\}$ be two fuzzy topologies on X.

Then for τ_1, $cl(\alpha)=\alpha_2'$, $int\ (cl(\alpha))=\alpha_2$, $int\ (\alpha)=\alpha_2$, cl($int\ (\alpha)$)=$cl(\alpha_2)$= α_2'.

Therefore, $int\ (cl(\alpha))\wedge$cl($int\ (\alpha)$)=$\alpha_2 \wedge \alpha_2' = \alpha_2 \leq \alpha$.

Thus α is τ_1-fuzzy b-closed set in (X, τ_1, τ_2).

Then $\lambda = \alpha \vee \alpha_1 \in (\tau_1, \tau_2)$-$FbLO^*(X)$ but $\lambda = \alpha \vee \alpha_1 \notin (\tau_1, \tau_2)$-$FLO$ (X), because α is not τ_1-fuzzy closed set in (X, τ_1, τ_2).

Next let $\tau_1 = \{\underline{0}, \underline{1}, \alpha_1\}$ and $\tau_2 = \{\underline{0}, \underline{1}, \alpha_1, \alpha_2, \alpha_1 \vee \alpha_2, \alpha_1 \wedge \alpha_2\}$ be two fuzzy topologies on X and $\beta = \{a_{0.4}, b_{0.9}, c_0\}$ be a fuzzy set on X.

Then for τ_2, $int\ (cl(\beta))=\underline{1}$, cl($int\ (\beta)$)=$\underline{1}$.

Therefore, $\beta \leq int\ (cl(\beta))\vee$cl($int\ (\beta)$)=$\underline{1}$.

Thus β is τ_2-fuzzy b-open set in (X, τ_1, τ_2).

Then $\lambda_1 = \alpha_1' \vee \beta \in (\tau_1, \tau_2)$-$FbLO^{**}$ (X) but $\lambda_1 = \alpha_1' \vee \beta \notin (\tau_1, \tau_2)$-$FLO$ (X), because β is not τ_2-fuzzy open set in (X, τ_1, τ_2).

Theorem 2.8

Let α be a fuzzy subset of a fuzzy bitopological space (X, τ_1, τ_2). If $\alpha \in (\tau_1, \tau_2)$-$FbLO^*(X)$ then $\alpha \in (\tau_1, \tau_2)$-$FbLO(X)$.

Proof.

Let $\alpha \in (\tau_1, \tau_2)$-$FbLO^*(X)$, then there exists a τ_1-fuzzy b-closed set β and a τ_2-fuzzy open set γ such that $\alpha=\beta \vee \gamma$.

Since γ is τ_2-fuzzy open, we have $\gamma \leq int(cl(\gamma))$ and $\gamma \leq cl(int(\gamma))$.

Hence $\gamma \leq int(cl(\gamma)) \vee cl(int(\gamma))$. Thus γ is τ_2-fuzzy b-open set in (X, τ_1, τ_2).

Then there exists a τ_1-fuzzy b-closed set β and a τ_2-fuzzy b-open set γ such that $\alpha=\beta \vee \gamma$.

Therefore, $\alpha \in (\tau_1, \tau_2)$-$FbLO(X)$.

Remark 2.9

The converse of the above theorem is not always true. It follows from the following example:

Example 2.10

Let $X = \{a, b, c\}$ and consider the fuzzy sets on X, $\alpha_1 = \{a_{0.3}, b_0, c_{0.8}\}$, $\alpha_2 = \{a_{0.4}, b_0, c_{0.4}\}$, $\alpha = \{a_{0.4}, b_0, c_{0.5}\}$ and $\beta = \{a_{0.4}, b_0, c_{0.9}\}$. Let $\tau_1 = \tau_2 = \{\underline{0}, \underline{1}, \alpha_1, \alpha_2, \alpha_1 \vee \alpha_2, \alpha_1 \wedge \alpha_2\}$ be fuzzy topologies on X.

Then α is a τ_1-fuzzy b-closed set and β is a τ_2-fuzzy b-open set. Thus $\lambda = \alpha \vee \beta \in (\tau_1, \tau_2)\text{-}FbLO(X)$ but $\lambda \notin (\tau_1, \tau_2)\text{-}FbLO^*(X)$ because β is not τ_2-fuzzy open in X.

Theorem 2.11

Let α be a fuzzy subset of a fuzzy bitopological space (X, τ_1, τ_2). If $\alpha \in (\tau_1, \tau_2)\text{-}FbLO^{**}(X)$ then $\alpha \in (\tau_1, \tau_2)\text{-}FbLO(X)$.

Proof:

Can be established following standard techniques.

Remark 2.12

The converse of the above theorem is not always true. It follows from the following example:

Example 2.13

Let $X = \{a, b, c\}$ and consider the fuzzy sets on X are $\alpha_1 = \{a_0, b_{0.3}, c_{0.8}\}$, $\alpha_2 = \{a_0, b_{0.4}, c_{0.4}\}$, $\alpha = \{a_0, b_{0.4}, c_{0.5}\}$ and $\beta = \{a_0, b_{0.4}, c_{0.9}\}$. Let $\tau_1 = \tau_2 = \{\underline{0}, \underline{1}, \alpha_1, \alpha_2, \alpha_1 \vee \alpha_2, \alpha_1 \wedge \alpha_2\}$ be a fuzzy topologies on X.

Then α is a τ_1-fuzzy b-closed set and β is a τ_1-fuzzy b-open set. Thus $\lambda = \alpha \vee \beta \in (\tau_1, \tau_2)\text{-}FbLO(X)$ but $\lambda \notin (\tau_1, \tau_2)\text{-}FbLO^{**}(X)$ because α is not τ_1-fuzzy closed in X.

Theorem 2.14

Let α and b be any two fuzzy subsets of a fuzzy bitopological space (X, τ_1, τ_2). If $\alpha \in (\tau_1, \tau_2)\text{-}FbLO(X)$ and β is τ_1-fuzzy b-closed and τ_2-fuzzy b-open, then $\alpha \wedge \beta \in (\tau_1, \tau_2)\text{-}FbLO(X)$.

Proof:

Since $\alpha \in (\tau_1, \tau_2)\text{-}FbLO(X)$, then there exists a τ_1-fuzzy b-closed set α_1 and a τ_2-fuzzy b-open set α_2 such that $\alpha = \alpha_1 \vee \alpha_2$.

We have, $\alpha \wedge \beta = (\alpha_1 \vee \alpha_2) \wedge \beta = (\alpha_1 \wedge \beta) \vee (\alpha_2 \wedge \beta)$. Since β is τ_1-fuzzy b-closed and τ_2-fuzzy b-open, then $(\alpha_1 \wedge \beta)$ is τ_1-fuzzy b-closed and $(\alpha_2 \wedge \beta)$ is τ_2-fuzzy b-open.

Thus there exist a τ_1-fuzzy b-closed set $(\alpha_1 \wedge \beta)$ and a τ_2-fuzzy b-open set $(\alpha_2 \wedge \beta)$ such that $\alpha \wedge \beta = (\alpha_1 \wedge \beta) \vee (\alpha_2 \wedge \beta)$. Hence $\alpha \wedge \beta \in (\tau_1, \tau_2)\text{-}FbLO(X)$.

Theorem 2.15

Let $\alpha \in (\tau_1, \tau_2)\text{-}FbLO^*(X)$ and β be a τ_1-fuzzy closed and τ_2-fuzzy open subsets of (X, τ_1, τ_2), then $\alpha \vee \beta \in (\tau_1, \tau_2)\text{-}FbLO^*(X)$.

Proof:

Can be established following standard techniques.

Theorem 2.16

Let $\alpha \in (\tau_1, \tau_2)\text{-}FbLO^{**}(X)$ and β be a τ_1-fuzzy closed and τ_2-fuzzy open subsets of (X, τ_1, τ_2), then $\alpha \vee \beta \in (\tau_1, \tau_2)\text{-}FbLO^{**}(X)$.

Proof:

Can be established following standard techniques.

Theorem 2.17

Let α be a fuzzy subset of a fuzzy bitopological space (X, τ_1, τ_2). Then $\alpha \in (\tau_1, \tau_2)\text{-}FbLO^*(X)$ if and only if $\alpha = \beta \vee \tau_2\text{-int}(\alpha)$, for some τ_1-fuzzy b-closed set β.

Proof:

Let $\alpha \in (\tau_1, \tau_2)\text{-}FbLO^*(X)$. Then $\alpha = \beta \vee \gamma$, where β is τ_1-fuzzy b-closed and γ is τ_2-fuzzy open set in (X, τ_1, τ_2). Since $\beta \le \alpha$ and $\tau_2\text{-int}(\alpha) \le \alpha$, we have $\beta \vee \tau_2\text{-int}(\alpha) \le \alpha$ (1)

Further, $\tau_2\text{-int}(\alpha)^3\gamma$, therefore, $\beta \vee \tau_2\text{-int}(\alpha)^3\beta \vee \gamma = \alpha$ (2)

From (1) and (2), we have, $\alpha = \beta \vee \tau_2\text{-int}(\alpha)$.

Conversely, given that β is τ_1-fuzzy b-closed, we have, $\tau_2\text{-int}(a)$ is τ_2-open. Thus there exist a τ_1-fuzzy b-closed set β and a τ_2-open set $\tau_2\text{-int}(\alpha)$ in (X, τ_1, τ_2) such that $\alpha = \beta \vee_2\text{-int}(\alpha)$. Hence $\alpha \in (\tau_1, \tau_2)\text{-}FbLO^*(X)$.

Theorem 2.18

Let α and β be any two fuzzy sets of the fuzzy bitopological space (X, τ_1, τ_2). If $\alpha \in (\tau_1, \tau_2)\text{-}FbLO(X)$ and β is either τ_1-fuzzy b-closed or τ_2-fuzzy b-open, then $\alpha \vee \beta \in (\tau_1, \tau_2)\text{-}FbLO(X)$.

Proof:

Since $\alpha \in (\tau_1, \tau_2)\text{-}FbLO(X)$, then there exists a τ_1-fuzzy b-closed set α_1 and a τ_2-fuzzy b-open set α_2 such that $\alpha = \alpha_1 \vee \alpha_2$. We have, $\alpha \vee \beta = (\alpha_1 \vee \alpha_2) \vee \beta = (\alpha_1 \vee \beta) \vee \alpha_2$.

If β is τ_1-fuzzy b-closed, then $(\alpha_1 \vee \beta)$ is also τ_1-fuzzy b-closed.

Hence $\alpha \vee \beta \in (\tau_1, \tau_2)\text{-}FbLO(X)$.

Let β be τ_2-fuzzy b-open, then $\alpha \vee \beta = \alpha_1 \vee (\alpha_2 \vee \beta)$, where $\alpha_2 \vee \beta$ is τ_2-fuzzy b-open.

Thus $\alpha \vee \beta \in (\tau_1, \tau_2)\text{-}FbLO(X)$.

Theorem 2.19

Let α and β be any two fuzzy sets of the fuzzy bitopological space (X, τ_1, τ_2). If $\alpha \in (\tau_1, \tau_2)\text{-}FbLO^*(X)$ and β is either τ_1-fuzzy closed or τ_2-fuzzy open ,then $\alpha \vee \beta \in (\tau_1, \tau_2)\text{-}FbLO^*(X)$.

Proof:

Can be established following standard techniques.

Theorem 2.20

Let α and b be any two fuzzy sets of the fuzzy bitopological space (X, τ_1, τ_2). If $\alpha \in (\tau_1, \tau_2)\text{-}FbLO^{**}(X)$ and b is either τ_1-fuzzy closed or τ_2-fuzzy open ,then $\alpha \vee \beta \in (\tau_1, \tau_2)\text{-}FbLO^{**}(X)$.

Proof:

Can be established following standard techniques.

Theorem 2.21

If $\alpha, \beta \in (\tau_1, \tau_2)$-*FbLO* ($X$) then $\alpha \vee \beta \in (\tau_1, \tau_2)$-*FbLO* ($X$).

Proof:

Let $\alpha, \beta \in (\tau_1, \tau_2)$-*FbLO* ($X$). Then there exist τ_1-fuzzy b-closed sets α_1, β_1 and τ_2-fuzzy b-open sets α_2, β_2 such that $\alpha = \alpha_1 \vee \alpha_2$ and $\beta = \beta_1 \vee \beta_2$.

We have $\alpha \vee \beta = (\alpha_1 \vee \alpha_2) \vee (\beta_1 \vee \beta_2) = (\alpha_1 \vee \beta_1) \vee (\alpha_2 \vee \beta_2)$, where $(\alpha_1 \vee \beta_1)$ is τ_1-fuzzy b-closed set and $(\alpha_2 \vee \beta_2)$ is τ_2-fuzzy b-open set.

Hence $\alpha \vee \beta \in (\tau_1, \tau_2)$-*FbLO* ($X$).

Theorem 2.22

If $\alpha, \beta \in (\tau_1, \tau_2)$-*FbLO** ($X$) then $\alpha \vee \beta \in (\tau_1, \tau_2)$-*FbLO** ($X$).

Proof:

Can be established following standard techniques.

Theorem 2.23

If $\alpha, \beta \in (\tau_1, \tau_2)$-*FbLO*** ($X$) then $\alpha \vee \beta \in (\tau_1, \tau_2)$-*FbLO*** ($X$).

Proof:

Can be established following standard techniques.

Definition 2.24

Let (X, τ_1, τ_2) and (Y, ρ_1, ρ_2) be two bitopological spaces and $f:X \rightarrow Y$ be a mapping. Then f is said to be fuzzy locally continuous if the inverse image of each FLO-set of Y is FLO in X.

Definition 2.25

Let (X, τ_1, τ_2) and (Y, ρ_1, ρ_2) be two bitopological spaces and $f:X \rightarrow Y$ be a mapping. Then f is said to be fuzzy b-locally continuous if the inverse image of each FbLO-set of Y is FLO in X.

From the definition it is obvious that every fuzzy locally continuous function is fuzzy b-locally continuous but the converse may not be true (by Theorem 2.5 and Theorem 2.7).

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