ii- Open Set in Bitopological Spaces

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ABSTRACT

In this paper, we define *ii*-open set in bitopological space as follows: Let (X, τ_1, τ_2) be a bitopological space, a subset A of X is said to be ($\tau_1\tau_2 -$ *ii*- open set) if there exist $U,V \neq \emptyset, X$ and $U,V \in \tau_1 \cup \tau_2$ such that:

1. $A=int^1(U)$ or $A=int^2(V)$
2. $A \subseteq CL^1(A \cap U)$ or $A \subseteq CL^2(A \cap V)$

We study some characterizations and properties of this class. Also, we explain the relation between *ii*- open sets and open sets, *i*-open sets and α-open sets in bitopological space. Furthermore, we define *ii*- continuous mapping on bitopological spaces with some properties.

Keywords: α- open set, *i*- open set, *ii*- open set, bitopological space.

المجموعة المفتوحة من النمط – *ii* في الفضاءات التبولوجية الثنائية

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الملخص

في هذا البحث، عرفنا المجموعة المفتوحة من النمط – *ii* في الفضاء التبولوجي الثنائي على النحو التالي: ليكن (X, τ_1, τ_2) فضاء تبولوجي ثنائي، المجموعة الجزئية A من X تسمى (مجموعة مفتوحة من النمط-*ii* - $\tau_1\tau_2$) اذا وجد $U,V \neq \emptyset, X$ و $U,V \in \tau_1 \cup \tau_2$ بحيث ان:

1. $A=int^1(U)$ or $A=int^2(V)$
2. $A \subseteq CL^1(A \cap U)$ or $A \subseteq CL^2(A \cap V)$

درسنا بعض الصفات والخواص لهذا الصنف. ايضا وضحنا العلاقة بين المجاميع المفتوحة من النمط – *ii* والمجاميع المفتوحة، المجاميع المفتوحة من النمط – *i* والمجاميع المفتوحة من النمط–α في الفضاء التبولوجي الثنائي. اضافة الى ذلك، عرفنا التطبيق المستمر من النمط – *ii* على الفضاءات التبولوجية الثنائية مع بعض خصائصه.

الكلمات المفتاحية: مجموعة مفتوحة من النمط –α ، مجموعة مفتوحة من النمط –i ، مجموعة مفتوحة من النمط –ii ، فضاء تبولوجي ثنائي.

Introduction

The concept of bitopological space was introduced by Kelly [5] in 1963. A set equipped with two topologies is called a bitopological space and is denoted by (X, τ_1, τ_2), where (X, τ_1), (X, τ_2) are two topologicals spaces. Since then many authors have contributed to the development of various bitopological properties. Mohammed and Abdullah in 2019 [1], introduced the concept of *ii*-open sets as follows: A subset *A* of a topological space (X, τ) is said to be *ii*-open set if there exists an open set *G* in the topology of *X*, such that: $G \neq \emptyset, X$, $A \subseteq CL(A \cap G)$ and *int(A)=G*. later, the same authors in [2] studied topological properties of *ii*-derived, *ii*-border, *ii*-frontier, *ii*-exterior of a set by using the concept of *ii*-open sets. It is shown in [1] that each of $\tau \subset \tau^{ii}$ (the family of all ii-open sets) and τ^{ii} is a topology on *X*. Following Mahdi in [4] and Askandar and Mohammed in [3], we introduce the concept of *ii*-open set in bitopological space as follows: Let (X, τ_1, τ_2) be a bitopological space, a subset *A* of *X* is said to be ($\tau_1\tau_2 -$ *ii*- open set) if there exist $U, V \neq \emptyset, X$ and $U, V \in \tau_1 \cup \tau_2$ such that:

1. $A = int^1(U)$ *or* $A = int^2(V)$
2. $A \subseteq CL^1(A \cap U)$ *or* $A \subseteq CL^2(A \cap V)$

The aim of this paper is to study $\tau_1\tau_2 -$ *ii*- open set with their properties and characterizations in bitopological space (X, τ_1, τ_2). Further, we study the comparison of this class with other classes namely: $\tau_1\tau_2 -$ open, $\tau_1\tau_2 -$ *i*- open and $\tau_1\tau_2 - \alpha$ open sets. This work consists of three sections. In the first one, we define *ii*-open sets in bitopological spaces and we give many related examples. In the second section, we discuss the relationship between *ii*-open sets with open, *i*-open and α-open sets in bitopological spaces. In the third section, we define *ii*-continuous mapping on bitopological spaces and we study the relation between this type of mapping with continuous, α- continuous [7] and *i*- continuous mapping [3] .

1. *ii*-Open Sets in Bitopological Spaces

In this section, we recall the following definitions, which are useful in the sequel.

Definition 1.1 [3,6,7]: Let (X, τ_1, τ_2) be a bitopological space, a subset A of X is said to be

1. ($\tau_1\tau_2 -$ open set) [6] if $A \in \tau_1 \cup \tau_2$
2. ($\tau_1\tau_2 - \alpha$- open set) [7] if $A \subseteq \tau_1 - int(\tau_2 - cl(\tau_1 - int(A))$
3. ($\tau_1\tau_2 -$ *i*- open set) [3] if there exists $\tau_1 -$ open set $(G \neq \emptyset, X)$ such that $A \subseteq \tau_2 - CL(A \cap G)$. The complement of ($\tau_1\tau_2 -$ *i*- open set) is called ($\tau_1\tau_2 -$ *i*- closed set).

Definition 1.2: Let (X, τ_1, τ_2) be a bitopological space, a subset *A* of *X* is said to be $\tau_1\tau_2 -$ *ii*- open set if there exists $U, V \neq \emptyset, X$ and $U, V \in \tau_1 \cup \tau_2$ such that:

1. $A = int^1(U)$ or $A = int^2(V)$
2. $A \subseteq CL^1(A \cap U)$ or $A \subseteq CL^2(A \cap V)$

The complement of $\tau_1\tau_2 -$ *ii*- open set is called $\tau_1\tau_2 -$ *ii*- closed set .

Example 1.1: Let $X = \{a, b, c\}$, $\tau_1 = \{\emptyset, X, \{a\}, \{b\}, \{a, b\}\}$, $\tau_2 = \{\emptyset, X, \{a\}, \{c\}, \{a, c\}\}$

$\tau_1 \cup \tau_2 = \{\emptyset, X, \{a\}, \{b\}, \{c\}, \{a, b\}, \{a, c\}\}$

$\tau_1 -$ *closed sets are:* $\{\emptyset, \{b, c\}, \{a, c\}, \{c\}, X\}$

$\tau_2 -$ *closed sets are*: $\{\emptyset, \{b, c\}, \{a, b\}, \{b\}, X\}$

1. $A = \{a\}$ $U = \{a\}$ $V = \{a,b\}$
   $\{a\} = int^1\{a\} = \{a\}$ $\{a\} \subseteq CL^1(\{a\} \cap \{a\}) = \{a,c\}$
2. $A = \{b\}$ $U = \{b\}$ $V = \{a,b\}$
   $\{b\} = int^1\{b\} = \{b\}$ $\{b\} \subseteq CL^1(\{b\} \cap \{b\}) = \{b,c\}$
3. $A = \{c\}$ $U = \{c\}$ $V = \{a,c\}$
   $\{c\} = int^1\{c\} = \emptyset$ $\{c\} = int^2\{c\} = \{c\}$
   $\{c\} \subseteq CL^1(\{c\} \cap \{c\}) = \{c\}$
4. $A = \{a,b\}$ $U = \{a,b\}$ $V = \{b\}$
   $\{a,b\} = int^1\{a,b\} = \{a,b\}$ $\{a,b\} \subseteq CL^1(\{a,b\} \cap \{a,b\}) = X$
5. $A = \{a,c\}$ $U = \{a,c\}$ $V = \{c\}$
   $\{a,c\} = int^1\{a,c\} \neq \{a\}$ $\{a,c\} = int^2\{a,c\} = \{a,c\}$
   $\{a,c\} \subseteq CL^1(\{a,c\} \cap \{a,c\}) = \{a,c\}$
6. $A = \{b,c\}$ $U = \{c\}$ $V = \{b\}$
   $\{b,c\} = int^1\{b,c\} \neq \{b\}$ $\{b,c\} \subseteq CL^1(\{b,c\} \cap \{b\}) = \{b,c\}$
   $\{b,c\} = int^2\{b,c\} \neq \{c\}$

$\tau_1\ \tau_2 - ii - open\ sets\ are$: $\{\emptyset, X, \{a\}, \{b\}, \{c\}, \{a,b\}, \{a,c\}\}$

$\tau_1\ \tau_2 - ii - closed\ sets\ are$: $\{\emptyset, X, \{b,c\}, \{a,c\}, \{a,b\}, \{c\}, \{b\}\}$

Example 1.2: Let $X = \{a,b,c,d\}$,
$\tau_1 = \{\emptyset, X, \{a\}, \{b,c,d\}$, $\tau_2 = \{\emptyset, X, \{a\}, \{c\}, \{a,c\}\}$
$\tau_1 \cup \tau_2 = \{\emptyset, X, \{a\}, \{c\}, \{a,c\}, \{b,c,d\}\}$
$\tau_1 - closed\ sets\ are$: $\{\emptyset, X, \{b,c,d\}, \{a\}\}$
$\tau_2 - closed\ sets\ are$: $\{\emptyset, X, \{b,c,d\}, \{a,b,d\}, \{b,d\}\}$. By using the definition (1.2) we get the $\tau_1\ \tau_2 - ii - open\ sets\ are$: $\{\emptyset, X, \{a\}, \{c\}, \{a,c\}, \{b,c,d\}\}$

2. Some Properties of *ii*-Open Sets in Bitopological Spaces.

Definition 2.1: Let (X, τ_1, τ_2) be a bitopological space and let A be a subset of X. Recall that:

1. The intersection of all *ii*-closed sets containing A is called *ii*-closure of A, denoted by $\tau_1\ \tau_2 - clii(A)$.
2. The union of all *ii*-open sets contained in A is called *ii*-interior of A, denoted by $\tau_1\ \tau_2 - intii(A)$.

Theorem 2.2: Let (X, τ_1, τ_2) be a bitopological space and $A \subseteq X$ then, the following are true:

1. $\tau_1\ \tau_2 - intii(A)$ *is* $\tau_1\ \tau_2 - ii - open\ set$.
2. $\tau_1\ \tau_2 - clii(A)$ is $\tau_1\ \tau_2 - ii - closed\ set$.
3. If A is $\tau_1\ \tau_2 - ii - closed\ then$, $A = \tau_1\ \tau_2 - clii(A)$.
4. If A is $\tau_1\ \tau_2 - ii - open\ then$, $A = \tau_1\ \tau_2 - intii(A)$.
5. If $A \subset B$ then, $\tau_1\ \tau_2 - clii(A) \subset \tau_1\ \tau_2 - clii(B)$.
6. X - $\tau_1\ \tau_2 - clii(A) = \tau_1\ \tau_2 - intii(X - A)$.
7. X - $\tau_1\ \tau_2 - intii(A) = \tau_1\ \tau_2 - clii(X - A)$.
8. $x \in \tau_1\ \tau_2 - clii(A)$ iff for all *ii*-open set G containing A, $A \cap G \neq \emptyset$.

Proof: (1), (2), (3), (4) it follows from the definition (1.2).

5. Let $A \subset B$. Since $\tau_1\ \tau_2 - clii(A)$ is the smallest *ii*-closed set containing A, then $A \subset \tau_1\ \tau_2 - clii(A)$, So $B \subset \tau_1\ \tau_2 - clii(B)$. We get $\tau_1\ \tau_2 - clii(A) \subset \tau_1\ \tau_2 - clii(B)$.
6. $X \in X$ - $\tau_1 \tau_2 - clii(A)$ if $x \notin X$ - $\tau_1\tau_2 - clii(A)$, then for all $G \in \tau_1 \tau_2 - iio(X)$ containing x , then $A \cap G \neq \emptyset$ if and only if $x \in G \subset X - A$ if and only if $x \in \tau_1 \tau_2 - intii(X - A)$.
7. In a similar way to proof (6).
8. Let $x \in \tau_1\ \tau_2 - clii(A)$ we shall prove that $A \cap G \neq \emptyset$ for all ii-open set G containing x. Let there exists set G is $\tau_1\ \tau_2 - ii - open$ containing x such that $A \cap G = \emptyset$, so $A \subseteq G^c$ and G^c is $\tau_1\ \tau_2 - ii - closed$ set, therefore $\tau_1\tau_2 - clii(A) \subset \tau_1\tau_2 - clii(G^c)$. Since $x \in \tau_1\ \tau_2 - clii(A)$ this implies that $x \in \tau_1\ \tau_2 - clii(G^c)$. Since G^c is $\tau_1\ \tau_2 - ii - closed$ set by theorem(2.2)(3) $x \in G^c$ means that $x \notin G$. Therefore $A \cap G \neq \emptyset$ for all $\tau_1\ \tau_2 - open$ sets G containing x.

Converse: Let $A \cap G \neq \emptyset$ for all G is $\tau_1 \tau_2 - ii - open$ set containing x, we shall prove that $x \in \tau_1 \tau_2 - clii(A)$. Let $x \notin \tau_1 \tau_2 - clii(A)$ by definition (2.1), there exists $\tau_1 \tau_2 - ii - closed$ set F containing A such that $x \notin F$, so $x \in F^c$ and F^c is $\tau_1 \tau_2 - ii - open$ set. Therefore $A \cap F^c = \emptyset$. This implies a contradiction. Therefore $x \in \tau_1 \tau_2 - clii(A)$.■

Theorem 2.3: Every open set in bitopological space (X, τ_1 , τ_2) is $\tau_1\ \tau_2 - ii - open$

Proof: Let G be open set in bitopological space (X, τ_1 , τ_2):

1. If $G \in \tau_1$ we shall prove that G is $\tau_1\ \tau_2 - ii - open$. Put $U=G$, we get
   i. $G \subseteq CL^1(G \cap G) \subseteq CL^1(G)$
   ii. $G=int^1 (G)$ because $G \in \tau_1$
2. If $G \in \tau_2$, put $V=G$, we get
   iii. $G \subseteq CL^2(G \cap G) \subseteq CL^2(G)$
   iv. $G=int^2 (G)$ because $G \in \tau_2$

By using the definition (1.2) we get in both cases G is $\tau_1\ \tau_2 - ii - open$ set. The converse of the above theorem is not true in general as shown in the following example:

Example 2.4: Let $X = \{a, b, c\}$, $\tau_1 = \{ \emptyset, X, \{b\}, \{a, c\}$, $\tau_2 = \{\emptyset, X, \{c\}, \{a, b\}\}$
$\tau_1 \cup \tau_2 = \{\emptyset, X, \{b\}, \{c\}, \{a, c\}, \{a, b\}\}$
$\tau_1 -$ $closed\ sets\ are$: $\{ \emptyset, X, \{a, c\}, \{b\}\}$
$\tau_2 -$ $closed\ sets\ are$: $\{ \emptyset, X, \{c\}, \{a, b\}\}$. By using the definition (1.2) we get the $\tau_1\ \tau_2 - ii - open\ sets\ are$: $\{\emptyset, X, \{a\}, \{b\}, \{c\}, \{a, c\}, \{a, b\}\}$.
We see that $A=\{a\}$ is $\tau_1\ \tau_2 - ii - open\ set$ but A is not $\tau_1\ \tau_2 - open\ set$.

Remark 2.5: From the definition (1.2) we get every $\tau_1\ \tau_2 - ii - open$ set in bitopological space is $\tau_1\ \tau_2 - i - open$ set. The converse of the above remark is not true in general as shown in the following example:

Example 2.6: Let $X = \{a, b, c\}$, $\tau_1 = \{ \emptyset, X, \{a\}$, $\tau_2 = \{\emptyset, X, \{a\}, \{a, b\}\}$
$\tau_1 \cup \tau_2 = \{\emptyset, X, \{a\}, \{a, b\}\}$
$\tau_1 -$ $closed\ sets\ are$: $\{ \emptyset, X, \{b, c\}\}$
$\tau_2 -$ $closed\ sets\ are$: $\{ \emptyset, X, \{b, c\}, \{c\}\}$
$\tau_1\ \tau_2 - i - open\ sets\ are$: $\{\emptyset, X, \{a\}, \{a, b\}, \{a, c\}\}$
$\tau_1\ \tau_2 - ii - open\ sets\ are$: $\{\emptyset, X, \{a\}, \{a, b\}\}$
$A=\{a,c\}$ is $\tau_1\ \tau_2 - i - open\ set$ but A is not $\tau_1\ \tau_2 - ii - open\ set$.

Remark 2.7: We see that every $\tau_1\ \tau_2 - \alpha - open\ set$ in bitopological space is not necessary $\tau_1\ \tau_2 - ii - open\ set$, but this relation is true in topological spaces, that is, every $\alpha - open\ set$ in topological space is $ii - open\ set$ Theorem(2.12)[1]. Also, we see that every $\tau_1\ \tau_2 - ii - open\ set$ in bitopological space is not necessary $\tau_1\ \tau_2 - \alpha - open\ set$, it means that:

$$\tau_1\,\tau_2 - \alpha - open\ set \quad \not\rightleftarrows \quad \tau_1\ \tau_2 - ii - open\ set$$

As in the following examples:

Example 2.8:

Let $X = \{a, b, c, d\}$, $\tau_1 = \{\emptyset, X, \{a\}, \{b, c, d\}$, $\tau_2 = \{\emptyset, X, \{a\}, \{c\}, \{a, c\}\}$

$\tau_1 \cup \tau_2 = \{\emptyset, X, \{a\}, \{c\}, \{a, c\}, \{b, c, d\}\}$

$\tau_1 -\ closed\ sets\ are: \{\emptyset, X, \{b, c, d\}, \{a\}\}$

$\tau_2 -\ closed\ sets\ are: \{\emptyset, X, \{b, c, d\}, \{a, b, d\}, \{b, d\}\}$

$\tau_1\ \tau_2 - ii - open\ sets\ are: \{\emptyset, X, \{a\}, \{c\}, \{a, c\}, \{b, c, d\}\}$

$\tau_1\ \tau_2 - \alpha - open\ sets\ are: \{\emptyset, X, \{a\}, \{b, c, d\}\}$

$A=\{c\}$ is $\tau_1\ \tau_2 - ii - open\ set$ but A is not $\tau_1\ \tau_2 - \alpha - open\ set$

Example 2.9: Let $X = \{a, b, c\}$, $\tau_1 = \{\emptyset, X, \{a\}\}$, $\tau_2 = \{\emptyset, X, \{a\}, \{a, b\}\}$

$\tau_1 \cup \tau_2 = \{\emptyset, X, \{a\}, \{a, b\}\}$

$\tau_1 -\ closed\ sets\ are: \{\emptyset, X, \{b, c\}\}$

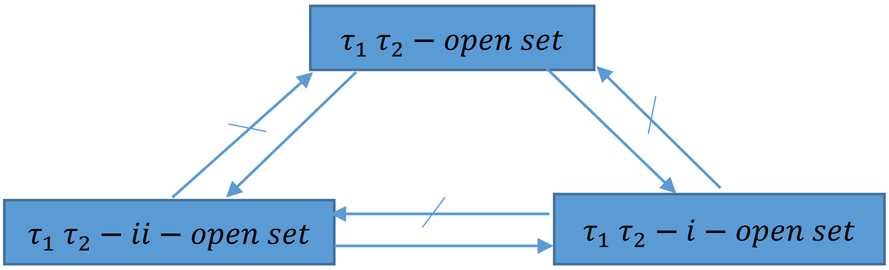
$\tau_2 -\ closed\ sets\ are: \{\emptyset, X, \{b, c\}, \{c\}\}$

$\tau_1\ \tau_2 - ii - open\ sets\ are: \{\emptyset, X, \{a\}, \{a, b\}\}$

$\tau_1\ \tau_2 - \alpha - open\ sets\ are: \{\emptyset, X, \{a\}, \{a, b\}, \{a, c\}\}$

$A=\{a, c\}$ is $\tau_1\ \tau_2 - \alpha - open\ set$ but A is not $\tau_1\ \tau_2 - ii - open$ set.

Remark 2.10: From the above results we get the following diagram.



3. *ii*- Continuity on Bitopological Spaces.

In this section, we define *ii*-continuous mapping from (X, τ_1, τ_2) in (Y, δ_1, δ_2) by using the definition of *ii*-open sets in topological space (X, τ) see[1],[2] . Also, we study the relation between *ii*-continuous mapping on bitopological spaces with continuous and *i*-continuous mapping [3].

Definition 3.1: A mapping $f: (X, \tau_1, \tau_2) \rightarrow (Y, \delta_1, \delta_2)$ is called

1. Continuous if $f^{-1}(G)$ is $\tau_1\ \tau_2 - open\ set$ in (X, τ_1, τ_2) for any open set G in (Y, δ_1, δ_2).
2. i-Continuous if f^{-1}(G) is $\tau_1\ \tau_2 - i - open\ set$ in (X, τ_1, τ_2) for any open set G in (Y, δ_1, δ_2).

Definition3.2: A mapping $f: (X, \tau_1, \tau_2) \to (Y, \delta_1, \delta_2)$ is called *ii*-continuous if f^{-1}(G) is $\tau_1\ \tau_2 - ii - open\ set$ in (X, τ_1, τ_2) for any open set G in (Y, δ_1, δ_2).

Theorem 3.3: Let $f: (X, \tau_1, \tau_2) \to (Y, \delta_1, \delta_2)$ be mapping then:

1. Every continuous mapping is an *ii*-continuous,
2. Every *ii*-continuous mapping is an *i*-continuous.

***Proof*:** (1) Let G be an open set in (Y, δ_1, δ_2). Since f is continuous, it follows that f^{-1}(G) is $\tau_1\ \tau_2 - open\ set$ in (X, τ_1, τ_2). By Theorem (2.3). Hence f^{-1}(G) is $\tau_1\ \tau_2 - ii - open\ set$ in (X, τ_1, τ_2). Thus f is *ii*-continuous.

(2) Let G be open set in (Y, δ_1, δ_2). Since f is *ii*-continuous, it follows that f^{-1}(G) is $\tau_1\ \tau_2 - ii - open\ set$ in (X, τ_1, τ_2). By remark (2.5). Hence f^{-1}(G) is $\tau_1\ \tau_2 - i - open\ set$ in (X, τ_1, τ_2). Thus f is *i*-continuous.■

The converse of the above theorem is not true in general as shown in the following example:

Example 3.4: Let $X = Y = \{a, b, c\}, \tau_1 = \{\emptyset, X, \{a\}, \ \tau_2 = \{\emptyset, X, \{a\}, \{a, b\}\}$

$\delta_1 = \{\emptyset, Y, \{a\}, \{a, c\}\}, \quad \delta_2 = \{\emptyset, Y, \{a, c\}\}$

$\tau_1 \cup \tau_2 = \{\emptyset, X, \{a\}, \{a, b\}\}$

$\tau_1 -\ closed\ sets\ are: \{\emptyset, X, \{b, c\}\}$

$\tau_2 -\ closed\ sets\ are: \{\emptyset, X, \{b, c\}, \{c\}\}$

$\tau_1\ \tau_2 - ii - open\ sets\ are: \{\emptyset, X, \{a\}, \{a, b\}\}$

$\tau_1\ \tau_2 - i - open\ sets\ are: \{\emptyset, X, \{a\}, \{a, b\}, \{a, c\}\}$

Let $f: (X, \tau_1, \tau_2) \to (Y, \delta_1, \delta_2)$ be the identity mapping then $f^{-1}(\{a\})=\{a\}$, $f^{-1}(\{b\})=\{b\}$, $f^{-1}(\{c\})=\{c\}$. Then f is *i*-continuous on bitopological spaces but f is not *ii*-continuous, Since $\{a, c\}$ is open set in (Y, δ_1, δ_2) $f^{-1}(\{a,c\})=\{a,c\}$ is not $\tau_1\ \tau_2 - ii - open\ set$ in (X, τ_1, τ_2).

Conclusion 3.5:

For future, also we can study the concept of $\tau_1\ \tau_2 - ii - open$ mapping and $\tau_1\ \tau_2 - ii - homeomorphisem$ and other topological concepts between bitopological spaces $(X, \tau_1, \tau_2)\ and\ (Y, \delta_1, \delta_2)$.

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