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Weak Forms of Bioperation-Preopen Sets

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Abstract: In this paper we introduce and study the notions minimal $[\gamma,\gamma']$-preclosed sets and maximal $[\gamma,\gamma']$-preopen sets in a topological space (X,τ).

Keywords: *minimal $[\gamma,\gamma']$-preclosed sets and maximal $[\gamma,\gamma']$-preopen sets.*

1. INTRODUCTION

Generalized open sets play a very important role in General Topology and they are now the research topics of many topologists worldwide. Indeed a significant theme in General Topology and Real analysis concerns the various modified forms of continuity, separation axioms etc.by utilizing generalized open sets. Kasahara [1] defined the concept of an operation on topological spaces. Maki and Noiri [3] introduced the notions of $\tau_{[\gamma,\gamma']}$, which is the collection of all $[\gamma,\gamma']$-open sets in a topological space. In this paper we introduce and study the notions (X,τ) minimal $[\gamma,\gamma']$-preclosed sets and maximal $[\gamma,\gamma']$-preopen sets in a topological space (X,τ).

2. PREILIMINARIES

The closure and interior of a subset A of (X,τ) are denoted by Cl(A) and Int(A), respectively.

Definition 2.1

[1] Let (X,τ) be a topological space. An operation γ on the topology τ is function from τ on to power set Ƥ(X) of X such that $V \subset V^{\gamma}$ for each $V \in \tau$,where V^{γ} denotes the value of τ at V. It is denoted by $\gamma:\tau \to$ Ƥ(X).

Definition 2.2

[3] A topological space (X,τ) equipped with two operations namely γ and γ' defined on τ is called a bioperation-topological space and it is denoted by (X,τ,γ,γ').

Definition 2.3

A subset A of a topological space (X,τ) is said to be $[\gamma,\gamma']$-open set is [3] if for each $x \in A$ there exist open neighbourhoods U and V of x such that $U^{\gamma} \bigcap V^{\gamma'} \subset A$. The complement of a $[\gamma,\gamma']$-open set is called a $[\gamma,\gamma']$-closed set. Also $\tau_{[\gamma,\gamma']}$ denotes set of all $[\gamma,\gamma']$-open sets in (X,τ).

Definition 2.4

[3] For a subset A of (X,τ), $\tau_{[\gamma,\gamma']}$-Cl(A) denotes the intersection of all $[\gamma,\gamma']$-closed sets containing A, that is
$\tau_{[\gamma,\gamma']} - Cl(A) = \bigcap\{F : A \subset F, X \setminus F \in \tau_{[\gamma,\gamma']}\}$.

Definition 2.5

Let A be any subset of X. The $\tau_{[\gamma,\gamma']}$-Int(A) is defined as $\tau_{[\gamma,\gamma']} - Int(A) = \bigcup\{U : U$ is a $[\gamma,\gamma']$-open set and $U \subset A\}$

Definition 2.6

A subset A of a topological space (X,τ) is said to be $[\gamma,\gamma']$-preopen [2] if
$A \subset \tau_{[\gamma,\gamma']} - Int(\tau_{[\gamma,\gamma']} - Cl(A))$.

3. MAXIMAL AND MINIMAL SETS VIA BIOPERATION-SEMIOPEN SETS

In this section, we introduce and study minimal $[\gamma,\gamma']$-preclosed sets and maximal $[\gamma,\gamma']$-preopen sets in a bioperation-topological space (X,τ,γ,γ').

Definition 3.1

A proper nonempty $[\gamma,\gamma']$-preclosed subset F of a bioperation-topological space (X,τ,γ,γ') is said to be a minimal $[\gamma,\gamma']$-preclosed set if any $[\gamma,\gamma']$-preclosed set contained in F is ϕ or F.

Definition 3.2

A proper nonempty $[\gamma,\gamma']$-preopen U of a bioperation-topological space (X,τ,γ,γ')

is said to be a maximal $[\gamma,\gamma']$-preopen set if any $[\gamma,\gamma']$-preopen set containing U is either X or U.

The following theorem shows the relation between minimal $[\gamma,\gamma']$-preclosed sets and maximal $[\gamma,\gamma']$-preopen sets

Theorem 3.3. *A proper nonempty subset U of a bioperation-topological space* (X,τ,γ,γ') *is a maximal* $[\gamma,\gamma']$*-preopen if and only if* $X\setminus U$ *is minimal* $[\gamma,\gamma']$*- preclosed.*

Proof. Let U be a maximal $[\gamma,\gamma']$-preopen set. Suppose $X\setminus U$ is not minimal $[\gamma,\gamma']$-preclosed set. Then there exists a $[\gamma,\gamma']$-preclosed set $V\neq X\setminus U$ such that $\phi\neq V\subset X\setminus U$. That is $U\subset X\setminus U$ and $X\setminus V$ is a $[\gamma,\gamma']$-preopen set, which is a contradiction for U is a minimal $[\gamma,\gamma']$-preclosed set. Conversely, let X\U be a minimal $[\gamma,\gamma']$-preclosed set. Suppose U is not a maximal $[\gamma,\gamma']$-preopen set. Then there exists a $[\gamma,\gamma']$-preopen set $E\neq U$ such that $U\subset E\neq X$. That is $\phi\neq X\setminus E\subset X\setminus U$ and $X\setminus E$ is a $[\gamma,\gamma']$-preclosed set, which is a contradiction for X\U is a minimal $[\gamma,\gamma']$-preclosed set. Therefore, U is a maximal $[\gamma,\gamma']$-preclosed set.

Lemma 3.4. *For the subsets U and V be any two subsets of a bioperation-topological space* (X,τ,γ,γ')*, we have the following:*

1. *If U is minimal* $[\gamma,\gamma']$*-preclosed and V a* $[\gamma,\gamma']$*-preclosed set, then* $U\cap V=\phi$ *or* $U\subset V$.
2. *If U and V are minimal* $[\gamma,\gamma']$*-preclosed sets, then* $U\cap V=\phi$ *or* $U=V$.

Proof. (1). If $U\cap V\neq\phi$, then there is nothing to prove. If $U\cap V\neq\phi$, then $U\cap V\subset U$. Since U is a minimal $[\gamma,\gamma']$-preclosed set, $U\cap V=U$. Hence $U\subset V$.
(2). If $U\cap V\neq\phi$, then $U\subset V$ and $V\subset U$ by (1). Hence $U=V$.

Theorem 3.5. Let *U be a minimal* $[\gamma,\gamma']$*-preclosed subset of a bioperation-topological space* (X,τ,γ,γ'). *If* $x\in U$ *,then* $U\subset W$ *for some* $[\gamma,\gamma']$*-preclosed set W containing x.*

Proof. Let $x\in U$ and W be a $[\gamma,\gamma']$-preclosed set such that $x\in G$. Then $U\cap W\neq\phi$. By Lemma 3.4(1), $U\subset W$.

Theorem 3.6. Let *U be a minimal* $[\gamma,\gamma']$*-preclosed subset of a bioperation-topological space* (X,τ,γ,γ'), *Then* $U=\bigcap\{W:W\in[\gamma,\gamma']-SC(X,x)\}$.

Proof. By Theorem 3.5 and U is a $[\gamma,\gamma']$-preclosed set containing x, we have $U\subset\bigcap\{W:W\in[\gamma,\gamma']-SC(X,x)\}$. Next let, $x\in\bigcap\{W:W\in[\gamma,\gamma']-SC(X,x)\}$. This imples that , $x\in W$ for all $[\gamma,\gamma']$-preclosed set W. As U is $[\gamma,\gamma']$-preclosed, $x\in U$; hence $\bigcap\{W:W\in[\gamma,\gamma']-SC(X,x)\}=U$.

Theorem 3.7. *Let U be a nonempty* $[\gamma,\gamma']$*-preclosed subset of a bioperation-topological space* (X,τ,γ,γ') *. Then the following statements are equivalent:*

(1) *U is a minimal* $[\gamma,\gamma']$*-preclosed set.*
(2) $U\subset[\gamma,\gamma']-pCl(S)$ *for any nonempty subset S of U.*
(3) $[\gamma,\gamma']-pCl(U)=[\gamma,\gamma']-pCl(S)$ *for any nonempty subset S of U.*

Proof. $(1)\Rightarrow(2)$: Let $x\in U$; U be a minimal $[\gamma,\gamma']$-preclosed set and $S(\neq\phi)\subset U$. By Theorem 3.5, for any $[\gamma,\gamma']$-preclosed set W containing x, $S\subset U\subset W$ gives $S\subset W$. Now $S=S\cap U\subset S\cap W$. Since $S\neq\phi, S\cap W\neq\phi$. Since W is any $[\gamma,\gamma']$-preclosed set containing x, by Theorem 3.5, $x\in[\gamma,\gamma']-pCl(S)$. That is, $x\in U\Rightarrow x\in[\gamma,\gamma']-pCl(S)$. Hence $U\subset[\gamma,\gamma']-pCl(S)$ for any nonempty subset S of U.

$(2)\Rightarrow(3)$: Let S be a nonempty subset of U. Then $[\gamma,\gamma']-pCl(S)\subset[\gamma,\gamma']-pCl(U)$. By (2), $[\gamma,\gamma']-pCl(U)\subset[\gamma,\gamma']-pCl([\gamma,\gamma']-pCl(S))$ $=[\gamma,\gamma']-pCl(S)$.
That is, $[\gamma,\gamma']-pCl(U)\subset[\gamma,\gamma']-pCl(S)$. We have $[\gamma,\gamma']-pCl(U)=[\gamma,\gamma']-pCl(S)$ for any nonempty subset S of U.

$(3)\Rightarrow(1)$: Suppose U is not a minimal $[\gamma,\gamma']$-preclosed set. Than there exists a nonempty $[\gamma,\gamma']$-preclosed set V such that $V\subset U$ and $V\neq U$. Now, there exists an element a in U such that $a\notin V$. That is , $[\gamma,\gamma'] - pCl(\{a\}) \subset [\gamma,\gamma'] - pCl(X \setminus V) = X \setminus V,$ as X\V is $[\gamma,\gamma']$-preclosed in X. It follows that $[\gamma,\gamma'] - pCl(\{a\}) \neq [\gamma,\gamma'] - pCl(U)$. This is a contradiction for $[\gamma,\gamma'] - pCl(\{a\}) = [\gamma,\gamma'] - pCl(U)$ for any $\{a\}(\neq \phi) \subset U$. Therefore, U is a minimal $[\gamma,\gamma']$-preclosed set.

Theorem 3.8. *If V is a nonempty finite $[\gamma,\gamma']$-preclosed subset of a bioperation-topological space (X,τ,γ,γ'), then there exists at least one (finite) minimal $[\gamma,\gamma']$-preclosed set U such that $U \subset V$.*

Proof. If V is a minimal $[\gamma,\gamma']$-preclosed set, we may set U=V. If V is not a minimal $[\gamma,\gamma']$-preclosed set, then there exists a (finite) $[\gamma,\gamma']$-preclosed set V_1 such that $\phi = V_1 \subset V$. If V_1 is a minimal $[\gamma,\gamma']$-preclosed set, we may U=V_1 . If V_1 is not a minimal $[\gamma,\gamma']$-preclosed set, then there exists a (finite) $[\gamma,\gamma']$-preclosed set V_2 such that $\phi = V_2 \subset V_1$. Continuing this process, we have a sequence of $[\gamma,\gamma']$-preclosed sets $V \supset V_1 \supset V_2 \supset V_3 \supset .... \supset V_k \supset .....$ Since V is a finite set, this process repeats only finitely many times and finally we get a minimal $[\gamma,\gamma']$-preclosed set U=V_n for some positive integer n.

Theorem 3.9. *Let U and U_α be minimal $[\gamma,\gamma']$-preclosed subsets of a bioperation-topological space (X,τ,γ,γ') for any element $\alpha \in \Delta$ If $U \subset \bigcup_{\alpha\in\Delta} U_\alpha$, then there exists an element $\alpha \in \Delta$ such that $U = U_\alpha$.*

Proof. Let $U \subset \bigcup_{\alpha\in\Delta} U_\alpha$. Then $U \cap (\bigcup_{\alpha\in\Delta} U_\alpha) = U$. That is $\bigcup_{\alpha\in\Delta}(U \cap U_\alpha) = U$. Also by lemma3.4 (2), $U \cap U_\alpha = \phi$ or $U = U_\alpha$ for any $\alpha \in \Delta$. It follows that there exists an element $\alpha \in \Delta$ such that $U = U_\alpha$.

Theorem 3.10. *Let U and U_α be minimal $[\gamma,\gamma']$-preclosed subsets of a bioperation-topological space (X,τ,γ,γ') for any $\alpha \in \Delta$ If $U \neq U_\alpha$ for any $\alpha \in \Delta$, then $\left(\bigcup_{\alpha\in\Delta} U_\alpha\right) \cap U = \phi$.*

Proof. Suppose that $\left(\bigcup_{\alpha\in\Delta} U_\alpha\right) \cap U = \phi$. Then there exists an element $\alpha \in \Delta$ such that $U \cap U_\alpha = \phi$. By Lemma 3.4 (2), we have $U = U_\alpha$, Which contradicts the fact $U \neq U_\alpha$ for any $\alpha \in \Delta$. Hence $\left(\bigcup_{\alpha\in\Delta} U_\alpha\right) \cap U = \phi$.

Theorem 3.11. *Let A and B be any two subsets of a bioperation-topological space (X,τ,γ,γ'). Then we have the following:*

(1) *If* A *is maximal $[\gamma,\gamma']$-preopen set and B a $[\gamma,\gamma']$-preopen set, then $A \bigcup B = X$ or $B \subset A$.*

(2) *Let A and B are maximal $[\gamma,\gamma']$-preopen set, then $A \bigcup B = X$ or $A = B$.*

Proof. (1). If $A \bigcup B = X$, then there is nothing to prove. If $A \bigcup B \neq X$, then $A \bigcup B$ is a $[\gamma,\gamma']$-preopen set such that $A \subset A \bigcup B$. Then $A \bigcup B = A$. Hence $B \subset A$.

(2). If $A \bigcup B \neq X$, then $A \bigcup B$ is a $[\gamma,\gamma']$-preopen set such that A, $B \subset A \bigcup B$, that is, $A \bigcup B = A$ and $A \bigcup B = B$. Hence $A = B$.

Theorem 3.12. *Let F be a maximal $[\gamma,\gamma']$-preopen subsets of a bioperation-topological space (X,τ,γ,γ'). If $x \in F$, then $S \subset F$ for some $[\gamma,\gamma']$-preopen set S containing x.*

Proof. Similar to the proof of Theorem 3.5.

Theorem 3.13. *Let A,B and C be three $[\gamma,\gamma']$-preopen sets of a bioperation-topological space (X,τ,γ,γ') such that $A \neq B$. If $A \bigcap B \subset C$, then either $A = C$ or $B = C$.*

Proof. If $A = C$, then there is nothing to prove. If $A \neq C$, then we have to prove B=C.

Now
$$\begin{aligned} B \cap C &= B \cap (C \cap X) \\ &= B \cap (C \cap (A \cup B)) \text{ (by Theorem 3.11 (2))} \\ &= B \cap ((C \cap A) \cup (C \cap B)) \\ &= (B \cap C \cap A) \cup (B \cap C) \\ &= (A \cap B) \cup (C \cap B) \\ &= (A \cap C) \cap B \end{aligned}$$

$= X \cap B = B$ (Since A and C are maximal $[\gamma,\gamma']$-preopen set by Theorem 3.11 (2), $A \cup C = X$).
That is, $B \cap C = B \Rightarrow B \subset C$. Since B and C are maximal $[\gamma,\gamma']$-preopen sets, we have $B = C$. Hence $B = C$.

Theorem 3.14. *Let (X,τ,γ,γ') be a bioperation-topological space. If A,B and C are maximal $[\gamma,\gamma']$-preopen sets which are different from each other, then $(A \cap B) \not\subset (A \cap C)$.*

Proof. Let $A \cap B \subset A \cap C$. Then $(A \cap B) \cup (C \cap B) \subset (A \cap C) \cup (C \cap B)$. That is, $(A \cap C) \cap B \subset C \cap (A \cup B)$. By Theorem 3.11 (2), $A \cup C = X = A \cup B$. Hence $X \cap B \subset C \cap X \Rightarrow B \subset C$. Thus from the definition of maximal $[\gamma,\gamma']$-preopen sets, we have $B = C$, which is a contradiction to the fact that A,B and C are different to each other. Therefore, $(A \cap B) \not\subset (A \cap C)$.

Theorem 3.15. *Let (X,τ,γ,γ') be a bioperation-topological space. If F is a maximal $[\gamma,\gamma']$-preopen set and x be an element of F, then F= $\bigcup\{S : S$ is an $[\gamma,\gamma']$-preopen set E such that $F \cup S \neq X\}$.*

Proof. Similar to the proof of Theorem 3.6.

Theorem 3.16. *Let (X,τ,γ,γ') be a bioperation-topological space. If F is proper nonempty cofinite $[\gamma,\gamma']$-preopen set, then there exists(cofinite) maximal $[\gamma,\gamma']$-preopen set E such that $F \subset E$.*

Proof. If F is a maximal $[\gamma,\gamma']$-preopen set, we may set E=F. If F is not a maximal $[\gamma,\gamma']$-preopen set, then there exists a (cofinite) $[\gamma,\gamma']$-preopen set F_1 such that $F \subset F_1 \neq X$. If F_1 is a maximal $[\gamma,\gamma']$-preopen set, we may set $E=F_1$. If F_1 is not a maximal $[\gamma,\gamma']$-preopen set, then there exists a (cofinite) $[\gamma,\gamma']$-preopen set $F_2 \neq X$ such that $F \subset F_1 \subset F_2 (\neq X)$. Continuing this process, we have a sequence of $[\gamma,\gamma']$-preopen sets such that $F \subset F_1 \subset F_2 \subset ..... \subset F_k \subset ....$ Since F is a cofinite set, this process repeats only finitely many times and finally we get a maximal $[\gamma,\gamma']$-preopen set $E = F$.

Theorem 3.17. *Let (X,τ,γ,γ') be a bioperation-topological space.Then we have the following:*

(1) Let A be a maximal $[\gamma,\gamma']$-preopen set and $x \in X \setminus A$. Then $X \setminus A \subset B$ for any $[\gamma,\gamma']$-preopen set B containing x.

(2) Let A be a maximal $[\gamma,\gamma']$-preopen set. Then either of the following (i) or (ii) holds:
   - *(i) For each $x \in X \setminus A$ and each $[\gamma,\gamma']$-preopen set B containing x, B=X.*
   - *(ii) There exists a $[\gamma,\gamma']$-preopen set B such that $X \setminus A \subset B$*

(3) Let A be a maximal $[\gamma,\gamma']$-preopen set. Then either of the following (i) or (ii) holds:
   - *(i) For each $x \in X \setminus A$ and each $[\gamma,\gamma']$-preopen set B containing x, $X \setminus A \subset B$.*
   - *(ii) There exists a $[\gamma,\gamma']$-preopen set B such that $X \setminus A = B$.*

Proof. (1). Since $x \in X \setminus A$, we have $B \not\subset A$ for any $[\gamma,\gamma']$-preopen set B containing x. Then by Theorem 3.11 (1), $A \cup B = X \Rightarrow X \setminus A \subset B$.

(2). If (i) holds, we are done. Let (i) do not hold. Then there exists an element $x \in X \setminus A$ and a $[\gamma,\gamma']$-preopen set B containing x such that $B \subset X$. Then by Theorem 3.11 (1), $A \cup B = X$ or $B \subset A$. But $B \not\subset A \Rightarrow A \cup B = X \Rightarrow X \setminus A \subset B$.

(3). If (ii) holds, we are done. Let (ii) do not hold. Then (by (i)) for each $x \in X \setminus A$ and each $[\gamma,\gamma']$-preopen set B containing x, $X \setminus A \subset B$. Hence by assumption $X \setminus A \subset B$.

Theorem 3.18. *Let A be a maximal $[\gamma,\gamma']$-preopen sets in a bioperation-topological space (X,τ,γ,γ'). Then either $[\gamma,\gamma'] - pCl(A) = X$ or $[\gamma,\gamma'] - pCl(A) = A$.*

Proof. Since A is maximal $[\gamma,\gamma']$-preopen set, only the following cases (i) and (ii) occur by Theorem 3.17 (3).

(i) For each $x \in X$ and $x \in X \setminus A$ and each $[\gamma,\gamma']$-preopen set B containing x, we have, $X \setminus A \subset B$: Let $x \in X \setminus A$ and B be any $[\gamma,\gamma']$-preopen set B containing x. Since $X \setminus A \neq B$, we have $B \cap A \neq \phi$ and hence $X \setminus A \subset [\gamma,\gamma'] - pCl(A)$. Since $X = A \cup (X \setminus A)$ $\subset A \cup [\gamma,\gamma'] - pCl(A)$ $= [\gamma,\gamma'] - pCl(A) \subset X$, $X = [\gamma,\gamma'] - pCl(A)$.

There exists a $[\gamma,\gamma']$-preopen set B such that $X \setminus A = B(\neq X)$: Since $X \setminus A = B$, a $[\gamma,\gamma']$-preopen set, A is a $[\gamma,\gamma']$-preclosed set $\Rightarrow [\gamma,\gamma'] - pCl(A)$.

Theorem 3.19. *Let A be a maximal $[\gamma,\gamma']$-preopen sets in a bioperation-topological space (X,τ,γ,γ'). Then either $[\gamma,\gamma'] - pInt(X \setminus A) = X \setminus A$ or $[\gamma,\gamma'] - pInt(X \setminus A) = \phi$.*

Proof. By Theorem 3.18, we have $[\gamma,\gamma'] - pCl(A) = A$ or $[\gamma,\gamma'] - pCl(A) = X$. That is $[\gamma,\gamma'] - pInt(X \setminus A) = X \setminus A$ or $[\gamma,\gamma'] - pInt(X \setminus A) = \phi$.

Theorem 3.20. *Let A be a maximal $[\gamma,\gamma']$-preopen sets and B be a nonempty subset of X\A in a bioperation-topological space (X,τ,γ,γ'). Then $[\gamma,\gamma'] - pCl(B) = X \setminus A$.*

Proof. Since $\phi \neq B \subset X \setminus A, W \cap B \neq \phi$ for any element $x \in X \setminus A$ and any $[\gamma,\gamma']$-preopen set W containing x, by Theorem 3.17 (1). Thus, $X \setminus A \subset [\gamma,\gamma'] - pCl(B)$. Since $X \setminus A$ is $[\gamma,\gamma']$-preclosed set and $B \subset X \setminus A$, we have $[\gamma,\gamma'] - pCl(B) \subset X \setminus A$.

Corollary 3.21. *Let A be a maximal $[\gamma,\gamma']$-preopen sets in a bioperation-topological space (X,τ,γ,γ') and $A \subset B$. Then $[\gamma,\gamma'] - pCl(B) = X$.*

Proof. Since $A \subset B \subset X$, there exist a nonempty subset F of $X \setminus A$ such that $B = A \cup F$. Hence we have,

$$[\gamma,\gamma'] - pCl(B) = [\gamma,\gamma'] - pCl(A \cup F)$$
$$\supset [\gamma,\gamma'] - pCl(A) \cup [\gamma,\gamma'] - pCl(F)$$
$$\supset A \cup (X \setminus A) = X \text{ (by Theorem 3.18)}$$

Theorem 3.22. *Let A be a maximal $[\gamma,\gamma']$-preopen sets in a bioperation-topological space (X,τ,γ,γ') and let $X \setminus A$ have at least two elements. Then $[\gamma,\gamma'] - pCl(X \setminus \{a\}) = X$ for any element a of $X \setminus A$.*

Proof. As $A \subset X \setminus \{a\}$, we have, by Corollary 3.21, $[\gamma,\gamma'] - pCl(X \setminus \{a\}) = X$.

Theorem 3.23. *Let A be a maximal $[\gamma,\gamma']$-preopen set and G be a proper subset of a bioperation-topological space (X,τ,γ,γ') with $A \subset G$. Then $[\gamma,\gamma'] - pInt(G) = A$.*

Proof. If $G = A$, then $[\gamma,\gamma'] - pInt(G) = [\gamma,\gamma'] - pInt(A) = A$. If $G \neq A$, then we have $A \subset G$. Thus $A \subset [\gamma,\gamma'] - pInt(G)$. Since A is maximal $[\gamma,\gamma']$-preopen, we also have $[\gamma,\gamma'] - pInt(G) \subset A$. Hence $[\gamma,\gamma'] - pInt(G) = A$.

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