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Review Paper

Soft Maximal open sets and Soft Paraopen sets in Soft Generalized Topological Spaces

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Abstract
In this paper, we introduced the notion of some new types of soft μ-open sets namely soft maximal μ-open sets and soft para μ-open sets in soft generalized topological spaces. Usingthe basic concepts, some of the properties of soft maximal μ-open sets and soft para μ-open sets in soft generalized topological spaces are investigated.

Key words: *soft generalized topology, soft μ-open set, soft maximal μ-open set, soft para μ-open set and soft μ-open neighbourhood.*
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I. Introduction:

In 1999 D. Molodtsov [10] initiated the concept of soft set theory as a mathematical tool for modelling uncertainties. A soft set is a collection of approximate descriptions of an object. Maji et al. [9] have further improved the theory of soft sets. N. Cagman et al. [1] modified the definition of soft sets which is similar to that of Molodtsov. Many researchers have worked on the topological structure of soft sets. Muhammad Shabir et al. [14] introducedsoft topological spaces. In 2002 A. Csaszar [5] introduced the concept of generalized topologyand also studied some of its properties. Sunil Jacob John et al. [6] introduced the concept of soft generalized topological spaces in 2014. Qays Shakir [12] introduced and studied the concept of minimal and maximal soft open sets in soft topological spaces. B. Roy and R. Sen [13] introduced the concept of maximal μ-open and minimal μ-closed sets via generalized topology.

Motivated by the above concepts, we extend our further study in soft maximal μ-open sets and soft para μ-open sets in soft generalized topological spaces and some of their properties are investigated.

II. Preliminaries:

Definition: 2.1 [7]
A soft set F_A on the universe U is defined by the set of ordered pairs

$$F_A = \{(e, f_A(e)) \,/\, e \in E,\ f_A(e) \in P(U)\}$$

where $f_A : E \longrightarrow P(U)$ such that $f_A(e) = \emptyset$ if $e \notin A$. Here f_A is called an approximate function of the soft set F_A. The value of $f_A(e)$ may be arbitrary. Some of them may be empty,some may have nonempty intersection. The set of all soft sets over U with E as the parameter set will be denoted by $S(U)_E$ or simply $S(U)$.

Definition: 2.2 [7]

Let $F_A \in S(U)$. If $f_A(e) = \emptyset$, for all $e \in E$, then F_A is called an empty soft set, denoted by $F_\emptyset$. $f_A(e) = \emptyset$ means there is no element in U related to the parameter e in E. Therefore we do not display such elements in the soft sets as it is meaningless to consider such parameters.

Definition: 2.3 [6]

Let $F_A \in S(U)$. If $f_A\ (e) = U,$ for all $e \in A$, then F_A is called an A-universal soft set, denoted by $F_{\tilde{A}}$. If A = E, then the A-universal soft set is called an universal soft set, denoted by $F_{\tilde{E}}$.

Definition: 2.4 [6]

Let $F_A \in S(U)$. Then, the soft complement of F_A, denoted by (F_A), is defined by the approximate function $f_{A^c}\ (e) = (f_A\ (e))$, where $(f_A(e))^c$ is the complement of the set $f_A\ (e)$, that is, $(f_A\ (e))^c = U \setminus f_A\ (e)$ for all $e \in E$.

Definition: 2.5 [6]

Let $F_A \in S(U)$. A Soft Generalized Topology (SGT) on F_A, denoted by μ (or) μ_{F_A} is a collection of soft subsets of F_A having the following properties:

i. $F_\emptyset \in \mu$

ii. $\{F_{A_i} \subseteq F_A \,/\, i \in J \subseteq N\} \subseteq \mu \implies \bigcup_{i \in J} F_{A_i} \in \mu$

The pair (F_A, μ) is called a Soft Generalized Topological Space (SGTS).
Observe that $F_A \in \mu$ must not hold.

Definition: 2.6 [6]

Let (F_A, μ) be a SGTS. Then every element of μ is called a soft μ-open set.

Definition 2.7 [7]

Let (F_A, μ) be a SGTS and $\alpha \in F_A$. If there is a soft μ-open set F_B such that $\alpha \in F_B$, then F_B is called a soft μ-open neighbourhood (or) soft μ-nbd of α. The set of all soft μ-nbds of α, denoted by $\psi\,(\alpha)$, is called the family of soft μ-nbds of α. i.e. $\psi\,(\alpha) = \{F_B / F_B \in \mu, \alpha \in F_B\}$.

Definition: 2.8 [7]

Let (F_A, μ) be a SGTS and $F_B \subseteq F_A$. Then the soft μ-interior of F_B, denoted by $i_\mu\ (F_B)$ is defined as the soft union of all soft μ-open subsets of F_B. Note that $i_\mu\ (F_B)$ is the largest soft μ-open set that is contained in F_B.

Definition: 2.9 [7]

Let (F_A, μ) be a SGTS and $F_B \subseteq F_A$. Then the soft μ-closure of F_B, denoted by $c_\mu\ (F_B)$ is defined as the soft intersection of all soft μ-closed super sets of F_B. Note that $c_\mu\ (F_B)$ is the smallest soft μ-closed superset of F_B.

Definition 2.10 [11]

A proper nonempty open subset U of X is said to be a maximal open set if any open set which contains U is X or U.

Definition 2.11 [12]

A proper nonempty soft open subset F_K of a soft topological space $(F_A, \tilde{\tau})$ is said to be maximal soft open set if any soft open set which contains F_K is F_A or F_K.

Definition: 2.12 [6]

A soft generalized topology μ on F_A is said to be strong if $F_A \in \mu$.

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Definition: 2.13 [16]

A proper non-empty soft μ-open subset F_K of a soft generalized topological space (F_A, μ) is said to be soft minimal μ-open set if any soft μ-open set which is contained in F_K is $F_\emptyset$ or F_K. The family of all soft minimal μ-open sets in a soft generalized topological space (F_A, μ) is denoted by $\mathcal{SM}_i\mu\mathcal{O}(F_A)$.

Definition: 2.14 [2]

Any open subset U of a topological space X is said to be a paraopen set if it is neither minimal open nor maximal open set.

III Soft Maximal μ-open sets:

Definition: 3.1

A proper non-empty soft μ-open subset F_K of a soft generalized topological space (F_A, μ) is said to be soft maximal μ-open set if any soft μ-open set which contains F_K is F_A or F_K. The family of all soft maximal μ-open sets in a soft generalized topological space (F_A, μ) is denoted by $\mathcal{SM}_a\mu\mathcal{O}(F_A)$.

Example: 3.2

Let $\mathcal{K} = \{\kappa_1, \kappa_2, \kappa_3, \kappa_4\}$, $E = \{x_1', x_2', x_3'\}$, $A = \{x_1', x_2'\}$,then $(F_A, \mu) = \{F_\emptyset, F_{A_1}, F_{A_2}, F_{A_3}, F_{A_4}\}$ is a soft generalized topological space where

$F_\phi = \{(x_1', \phi), (x_2', \phi)\}$
$F_A = \{(x_1', \{\kappa_1, \kappa_2, \kappa_3, \kappa_4\}), (x_2', \{\kappa_2, \kappa_3, \kappa_4\})\}$
$F_{A_1} = \{(x_1', \{\kappa_1, \kappa_2, \kappa_3\}), (x_2', \{\kappa_2, \kappa_3\})\}$
$F_{A_2} = \{(x_1', \{\kappa_1, \kappa_2\}), (x_2', \{\kappa_2, \kappa_3\})\}$
$F_{A_3} = \{(x_1', \{\kappa_3\}), (x_2', \{\kappa_2\})\}$
$F_{A_4} = \{(x_1', \{\kappa_1, \kappa_3\}), (x_2', \{\kappa_2\})\}$
Here F_{A_1} is a soft maximal μ-open set.
Then $\mathcal{SM}_a\mu\mathcal{O}(F_A)=\{(x_1', \{\kappa_1, \kappa_2, \kappa_3\}), (x_2', \{\kappa_2, \kappa_3\})\}$

Proposition: 3.3

Let F_M and F_N be soft μ-open subsets of a soft generalized topological space (F_A, μ). If F_M is a soft maximal μ-open set, then $F_M \tilde{\cup} F_N = F_A$ or $F_N \tilde{\subseteq} F_M$.

Proof:

Suppose $F_M \tilde{\cup} F_N \neq F_A$.Then $F_N \tilde{\subseteq} F_M \tilde{\cup} F_N$ and F_M is soft maximal μ-open set $F_M \tilde{\cup} F_N = F_M$. Hence $F_N \tilde{\subseteq} F_M$.

Proposition: 3.4

Let F_M and F_N be soft maximal μ-open subsets of a soft generalized topological space (F_A, μ). If F_M is a soft maximal μ-open set, then $F_M \tilde{\cup} F_N = F_A$ or $F_M = F_N$.

Proof:

Suppose $F_M \tilde{\cup} F_N \neq F_A$. Then $F_M \tilde{\subseteq} F_M \tilde{\cup} F_N$ and F_N is soft maximal μ-open set $F_M \tilde{\cup} F_N = F_M$. Hence $F_M \tilde{\subseteq} F_N$. Similarly, F_M is soft maximal μ-open set, we get $F_N \tilde{\subseteq} F_M$. Therefore $F_M = F_N$.

Proposition: 3.5

Let F_M be a soft maximal μ-open set of a soft generalized topological space (F_A, μ). If $\alpha \tilde{\in} F_M$, then $F_M \tilde{\cup} F_N = F_A$ or $F_N \tilde{\subseteq} F_M$, for any soft μ-open neighbourhood F_N of α.

Proof:

Let F_M be a soft maximal μ-open set and F_N be a soft μ-open neighbourhood of α. If $F_M \tilde{\cup} F_N = F_A$, then there is nothing to prove. Suppose $F_M \tilde{\cup} F_N \neq F_A$. Then $F_N \tilde{\subseteq} F_M \tilde{\cup} F_N$ and $F_M \tilde{\cup} F_N$ is a soft μ-open set, we have $F_M \tilde{\cup} F_N = F_A$ or $F_M \tilde{\cup} F_N = F_M$. But by our assumption $F_M \tilde{\cup} F_N \neq F_A$. Hence $F_M \tilde{\cup} F_N = F_M$ which implies $F_N \tilde{\subseteq} F_M$.

Proposition: 3.6

Let F_Z be a soft maximal μ-open set of a soft generalized topological space (F_A, μ). Then

$$F_Z = \tilde{\cup} \{F_X / F_X \tilde{\cup} F_Z \neq F_A \text{where } F_X \text{ is a soft μ} - \text{open neighbourhood of } \alpha\}$$

for any element $\alpha \tilde{\in} F_Z$.

Proof:

Let F_X be a soft μ-open neighbourhood of α. Then by proposition 3.5,

$F_Z \tilde{\subseteq} \tilde{\cup} \{F_X / F_X \tilde{\cup} F_Z \neq F_A \text{where } F_X \text{ is a soft μ} - \text{open neighbourhood of } \alpha\} \tilde{\subseteq} F_Z$.

Hence $F_Z = \tilde{\cup} \{F_X / F_X \tilde{\cup} F_Z \neq F_A \text{where } F_X \text{ is a soft μ} - \text{open neighbourhood of } \alpha\}$ for any element $\alpha \tilde{\in} F_Z$.

Proposition: 3.7

Every soft maximal μ-open set is a soft μ-open set.

Proof:

By definition 3.1, every soft maximal μ-open set is a soft μ-open set.

Proposition: 3.8

Let F_Y be a soft maximal μ-open set of a strong soft generalized topological space (F_A, μ) and $\alpha \tilde{\notin} F_Y$. Then $F_Y{}^{\tilde{c}} \tilde{\subseteq} F_V$ for any soft μ-open set F_V containing α.

Proof:

Let F_V be a soft μ-open set containing α and $\alpha \tilde{\notin} F_Y$ which implies $F_V \tilde{\nsubseteq} F_Y$. By proposition 3.3, $F_Y \tilde{\cup} F_V = F_A$ which means $F_Y{}^{\tilde{c}} \tilde{\subseteq} F_V$.

Proposition: 3.9

Let F_L be a soft maximal μ-open set of a strong soft generalized topological space (F_A, μ). Then either of the following holds:

(i). For each $\alpha \tilde{\in} F_L{}^{\tilde{c}}$ and any soft μ-open set F_Q containing α, we have $F_Q = F_A$.
(ii).There exists a soft μ-open set F_Q such that $F_L{}^{\tilde{c}} \tilde{\subseteq} F_Q$ and $F_Q \tilde{\subseteq} F_A$.

Proof:
Suppose (i) does not hold. Then there exists $\alpha \tilde{\in} F_L{}^{\tilde{c}}$ and a soft μ-open set F_Q containing α, such that $F_Q \tilde{\subseteq} F_A$ and by proposition 3.8, we get $F_L{}^{\tilde{c}} \tilde{\subseteq} F_Q$.

Proposition 3.10

Let F_L be a soft maximal μ-open set of a strong soft generalized topological space (F_A, μ). Then either of the following holds:

(i). For each $\alpha \tilde{\in} F_L{}^{\tilde{c}}$ and any soft μ-neighbourhood F_Q containing α, we have $F_L{}^{\tilde{c}} \tilde{\subseteq} F_Q$.
(ii).There exists a proper soft μ-open set F_Q such that $F_L{}^{\tilde{c}} = F_Q$.

Proof:

Suppose (ii) does not hold. Then there exists $\alpha \tilde{\in} F_L{}^{\tilde{c}}$ and a soft μ-neighbourhood F_Q containing α and by proposition 3.9, we get $F_L{}^{\tilde{c}} \tilde{\subseteq} F_Q$.

4. Soft Para μ-open sets:

Definition: 4.1

A proper non-empty soft μ-open subset F_K of a soft generalized topological space (F_A, μ) is said to be soft para μ-open set if it is neither a soft minimal μ-open set nor a soft maximal μ-open set. The family of all soft para μ-open sets in a soft generalized topological space (F_A, μ) is denoted by $\mathcal{SP}_a\mu O(F_A)$.

Example: 4.2

Consider $\mathcal{K}' = \{k_1', k_2', k_3', k_4'\}$, $\mathfrak{R}' = \{r_1', r_2', r_3'\}$, $\mathfrak{A} = \{r_1', r_2'\}$, then $(F_{\mathfrak{A}}, \mu) = \{F_\emptyset, F_{\mathfrak{A}_1}, F_{\mathfrak{A}_2}, F_{\mathfrak{A}_3}\}$ is a soft generalized topological space where

$F_\emptyset = \{(r_1', \emptyset), (r_2', \emptyset)\}$
$F_{\mathfrak{A}} = \{(r_1', \{k_1', k_2', k_3', k_4'\}), (r_2', \{k_1', k_3', k_4'\})\}$
$F_{\mathfrak{A}_1} = \{(r_1', \{k_1', k_2', k_4'\}), (r_2', \{k_1', k_4'\})\}$
$F_{\mathfrak{A}_2} = \{(r_1', \{k_1', k_2'\}), (r_2', \{k_4'\})\}$
$F_{\mathfrak{A}_3} = \{(r_1', \{k_2', k_4'\}), (r_2', \{k_1', k_4'\})\}$

Here F_{A_2} is a soft para μ-open set.
Then $SP_a\mu O\,(F_A) = \{(r_1', \{k_1', k_2'\}), (r_2', \{k_4'\})\}$

Proposition: 4.3

Every soft para μ-open set is a soft μ-open set. But the converse need not be true and is shown by the following illustration.

Example: 4.4

Let $\mathfrak{U}' = \{u_1', u_2', u_3', u_4', u_5'\}$,$\mathcal{E} = \{\hat{e_1}, \hat{e_2}, \hat{e_3}\}$, $\mathcal{A} = \{\hat{e_1}, \hat{e_2}\}$, then $(F_{\mathcal{A}}, \mu) = \{F_\emptyset, F_{\mathcal{A}_1}, F_{\mathcal{A}_2}, F_{\mathcal{A}_3}, F_{\mathcal{A}_4}\}$ is a SGTS where

$F_\emptyset = \{(\hat{e_1}, \emptyset), (\hat{e_2}, \emptyset)\}$
$F_{\mathcal{A}} = \{(\hat{e_1}, \{u_1', u_2', u_3', u_4'\}), (\hat{e_2}, \{u_1', u_2', u_4'\})\}$
$F_{\mathcal{A}_1} = \{(\hat{e_1}, \{u_1', u_2', u_3'\}), (\hat{e_2}, \{u_1', u_2'\})\}$
$F_{\mathcal{A}_2} = \{(\hat{e_1}, \{u_2', u_3'\}), (\hat{e_2}, \{u_1', u_2'\})\}$
$F_{\mathcal{A}_3} = \{(\hat{e_1}, \{u_3'\}), (\hat{e_2}, \{u_2'\})\}$
$F_{\mathcal{A}_4} = \{(\hat{e_1}, \{u_1', u_3'\}), (\hat{e_2}, \{u_2'\})\}$

Proposition: 4.5

Soft union and soft intersection of a soft para μ-open set need not be a soft para μ-open set.

Example: 4.6

Let $\mathcal{N}' = \{n_1', n_2', n_3', n_4', n_5'\}$, $P' = \{p_1', p_2', p_3'\}$, $\mathbb{A} = \{p_1', p_2'\}$, then $(F_{\mathbb{A}}, \mu) = \{F_\emptyset, F_{\mathbb{A}_1}, F_{\mathbb{A}_2}, F_{\mathbb{A}_3}, F_{\mathbb{A}_4}\}$ is a soft generalized topological space where

$F_\emptyset = \{(p_1', \emptyset), (p_2', \emptyset)\}$
$F_{\mathbb{A}} = \{(p_1', \{n_1', n_2', n_3', n_4'\}), (p_2', \{n_2', n_3', n_4'\})\}$
$F_{\mathbb{A}_1} = \{(p_1', \{n_1', n_2', n_3'\}), (p_2', \{n_2', n_3'\})\}$
$F_{\mathbb{A}_2} = \{(p_1', \{n_1', n_2'\}), (p_2', \{n_2', n_3'\})\}$
$F_{\mathbb{A}_3} = \{(p_1', \{n_3'\}), (p_2', \{n_2'\})\}$
$F_{\mathbb{A}_4} = \{(p_1', \{n_1', n_3'\}), (p_2', \{n_2'\})\}$

Proposition: 4.7

Let (F_A, μ) be a soft generalized topological space with a non-empty soft para μ-open subset F_P of (F_A, μ). Then there exists a soft minimal μ-open set F_R such that $F_R \tilde{\subseteq} F_P$.

Proof:

By definition of soft minimal μ-open set, it is clear that $F_R \tilde{\subseteq} F_P$.

Proposition 4.8

Let (F_A, μ) be a soft generalized topological space with a non-empty soft para μ-open subset F_D of (F_A, μ). Then there exists a soft maximal μ-open set F_S such that $F_D \tilde{\subseteq} F_S$.

Proof:

By definition of soft maximal μ-open set, it is clear that $F_D \tilde{\subseteq} F_S$.

Proposition 4.9

Let (F_A, μ) be a soft generalized topological space. Then the following holds:

(i). If F_W is a soft para μ-open set and F_C is a soft minimal μ-open set then $F_W \tilde{\cap} F_C = F_\emptyset$ or $F_C \tilde{\subseteq} F_W$.

(ii). If F_V is a soft para μ-open set and F_U is a soft maximal μ-open set then $F_U \tilde{\cup} F_V = F_A$ or $F_V \tilde{\subseteq} F_U$.

(iii). If F_M and F_T are soft para μ-open sets in (F_A, μ), then their intersection is either a soft para μ-open set or a soft minimal μ-open set.

Proof:

(i) Let F_W be a soft para μ-open set and F_C be a soft minimal μ-open set in (F_A, μ). If $F_W \tilde{\cap} F_C = F_\emptyset$, then there is nothing to prove. Suppose $F_W \tilde{\cap} F_C \neq F_\emptyset$, then $F_W \tilde{\cap} F_C$ is a soft μ-open set and $F_W \tilde{\cap} F_C \tilde{\subseteq} F_W$ which implies $F_C \tilde{\subseteq} F_W$.

(ii) Let F_V be a soft para μ-open set and F_U be a soft maximal μ-open set in (F_A, μ). If $F_U \tilde{\cup} F_V = F_A$, then the result follows. Suppose $F_U \tilde{\cup} F_V \neq F_A$, then $F_U \tilde{\cup} F_V$ is a soft μ-open set and $F_V \tilde{\subseteq} F_U \tilde{\cup} F_V$. Since F_U is a soft maximal μ-open set, $F_U \tilde{\cup} F_V = F_U$ which implies $F_V \tilde{\subseteq} F_U$.

(iii) If F_M and F_T are soft para μ-open sets in (F_A, μ). If $F_M \tilde{\cap} F_T$ is a soft para μ-open set then the proof is obvious. Suppose $F_M \tilde{\cap} F_T$ is not a soft para μ-open set. Then by definition, $F_M \tilde{\cap} F_T$ is a soft minimal μ-open set or a soft maximal μ-open set. If $F_M \tilde{\cap} F_T$ is a soft minimal μ-open set then the result is true. Suppose $F_M \tilde{\cap} F_T$ is not a soft minimal μ-open set, then $F_M \tilde{\cap} F_T \tilde{\subseteq} F_M$ and $F_M \tilde{\cap} F_T \tilde{\subseteq} F_T$ which is a contradiction to F_M and F_T are soft para μ-open sets (By Proposition 4.7). Therefore $F_M \tilde{\cap} F_T$ is a soft minimal μ-open set.

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