Locally Starplus-Compactness in \(L\)-Topological Spaces

A. R. Prasannan

Department of Mathematics, Maharaja Agrasen College, University of Delhi, Delhi, India

**ABSTRACT**

The notion of local starplus-compactness on an \(L\)-fuzzy topological space, which is an extension of the notion of local compactness in general topology, is introduced. It turns out that local starplus-compactness is finitely productive, closed hereditary and invariant under fuzzy continuous open surjections. Moreover, local starplus-compactness is a good extension of the notion of local compactness in general topology. Examples are included to show that local starplus-compactness is neither hereditary nor expansive, nor contractive.

**KEYWORDS**

\(L\)-fuzzy topological space; starplus-compactness; locally starplus-compactness; pseudo closed set

1. Introduction

The class of locally compact spaces is far more wider than the class of compact spaces. The locally compact spaces often arise in topology and applications of topology to geometry, analysis and algebra. For example, the study of locally compact abelian group forms the foundation of harmonic analysis. It is well known that every compact space is locally compact but the converse need not be true. For example, the Euclidean space \(\mathbb{R}\) is locally compact but not compact. Topological manifolds share the local properties of Euclidean space and hence are locally compact. A locally compact space can be imbedded in a compact space, which is its compactification. One of the simplest compactification of a space is the one point compactification, wherein one simply adjoins one new point to the space. The classical example of one point compactification is the embedding of the Gaussian plane of complex numbers into the Riemann sphere. The category of locally compact spaces has been applied in almost every subdiscipline of mathematics and hence it is important to formulate an appropriate version of local compactness in the \(L\)-fuzzy setting.

The notion of compactness in fuzzy topology have been thoroughly investigated by various authors (see [1–13]). However, a satisfactory theory for the localisation of the notion of compactness in fuzzy topology has not been established because of the absence of proper definition of subspace on an arbitrary fuzzy subset. Kudri and Warner [11] defined a notion of \(L\)-fuzzy local compactness on an \(L\)-fuzzy topology by using very compact neighbourhood instead of compact neighbourhood of a fuzzy point. In [9] Kohli and Prasannan introduced the notion of starplus-compactness for a fuzzy topological space and successfully applied it to study fuzzy topologies and fuzzy uniformities on function spaces [12,14].

**CONTACT**

A. R. Prasannan  
aprasannan@gmail.com

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In this paper we localise the notion of starplus-compactness on an \( L \)-topological space, which is an extension of the notion of local compactness to the \( L \)-fuzzy setting. It turns out that local starplus-compactness is finitely productive, closed hereditary and invariant under continuous open surjection. Moreover, local starplus-compactness is a good extension of the notion of local compactness in general topology. Examples are included to reflect upon that local starplus-compactness is neither hereditary nor expansive nor contractive.

2. Basic Definitions and Preliminaries

Throughout this paper \( X \) is a nonempty set, \( \langle L, \leq, V, \Lambda, \prime \rangle \) is a complete De Morgan algebra with the smallest element and the largest element are denoted by \( 0 \) and \( 1 \), respectively. An \( L \)-fuzzy subset on \( X \) is a mapping \( A : X \rightarrow L \). The symbol \( L^X \) will denote the set of all \( L \)-fuzzy sets (or \( L \)-sets, for short) on \( X \). The smallest element and the largest element in \( L^X \) are denoted by \( 0 \) and \( 1 \), respectively. A crisp subset \( A \) of \( X \) is denoted by its characteristic function \( \chi_A \in L^X \). The elements of \( L^X \) will be denoted by the letters \( A, B, C \) etc. If \( c \in L \), then the constant fuzzy set with value \( c \) is denoted by \( c \). The constant \( L \)-set taking each member of \( X \) into \( 0 \) and \( 1 \) are denoted by \( 0_x \) and \( 1_x \), respectively.

An element \( a \in L \) is said to be a prime element if \( a \geq b \land c \Rightarrow a \geq b \) or \( a \geq c \). The set of all non unit prime elements in \( L \) is denoted by \( P(L) \). An element \( a \in L \) is called a co-prime if \( a' \in P(L) \). The set of all non zero co-prime elements in \( L \) is denoted by \( M(L) \) and set of all non zero co-prime elements in \( L^X \) is denoted by \( M(L^X) \).

**Definition 2.1** ([3,12]): For an \( L \)-set \( A \) in \( X \), the set \( A(a) = \{ x \in X : A(x) \leq a, a \in P(L) \} \) is called the strong \( a \)-level set of \( A \). The set \( \{ x \in X : A(x) > 0 \} \) is called the support of \( A \) and is denoted by \( \text{supp}A \).

**Definition 2.2:** An \( L \)-fuzzy point on \( X \) is an \( L \)-set \( x_a \in L^X \), defined by

\[
x_a(y) = \begin{cases} 
a, & \text{if } y = x; \\
0, & \text{if } y \neq x.
\end{cases}
\]

An \( L \)-set \( A \) is said to contain a fuzzy point \( x_a \) if \( A(x) \geq a \), and it is denoted by \( x_a \leq A \).

An \( L \)-topological space (or \( L \)-space for short) is a pair \( (X, \tau) \), where \( \tau \subseteq L^X \) contains \( 0_X, 1_X \) and is closed for arbitrary suprima and finite infima. \( \tau \) is called an \( L \)-topology and members of \( \tau \) are called open \( L \)-sets.

**Definition 2.3** ([15]): An \( L \)-topological space \( (X, \tau) \) is said to be Hausdorff if for every pair of \( L \)-fuzzy points \( x_a, y_b \) in \( X \) with distinct supports there exist open \( L \)-sets \( A \) and \( B \) in \( X \) such that \( x_a \in A, y_b \in B \) and \( A \land B = 0 \).

**Definition 2.4** ([3,16,17]): If \( (X, \tau) \) is an \( L \)-topological space then for each \( a \in P(L) \), the collection \( i_a(\tau) = \{ A(a) : A \in \tau \} \) is a topology on \( X \); we shall call it the strong \( a \)-level topology. Finally, for an \( L \)-topology \( \tau \) on \( X \), \( i(\tau) \) is the topology generated by taking the collection \( \cup\{ i_a(\tau) : a \in P(L) \} \) as a subbase.

**Definition 2.5** ([10,17]): Let \( (X,T) \) be a topological space and let \( \omega_L(T) \) denote the collection of all lower semicontinuous functions from \( X \) into \( L \) equipped with the lower Scott
topology, i.e., $\omega_L(T) = \{ A \in L^X : A^{(a)} \in T \text{ for each } a \in L \}$. Then $\omega_L(T)$ is a laminated (also called stratified) $L$-topology ($L$-topology which contains all constant $L$-sets) on $X$ and is called the topologically generated $L$-topology of $T$ and the fts $(X, \omega_L(T))$ is called the topologically generated $L$-topological space (also called the induced $L$-topological space).

**Definition 2.7** ([10, 17]): Let $P$ be a notion in $\text{TOP}$ and let $\tilde{P}$ be its generalisation in the category $L - \text{FTS}$. Then $\tilde{P}$ is called a good $L$-extension of the notion $P$ if and only if there exists a functor $F$ from $\text{TOP}$ into $L - \text{FTS}$ such that

(i) $F$ maps $\text{TOP}$ isomorphically onto any important subcategory of $L - \text{FTS}$, and

(ii) An object $(X, T) \in \text{TOP}$ possesses the notion $P$ if and only if $F((X, T)) = (X, F(T))$ possesses the property $\tilde{P}$.

**Definition 2.8** ([13]): Let $(X, \tau)$ be an $L$-topology. An $L$-set $A \in L^X$ is called a pseudo closed fuzzy set with respect to the $L$-topological space $(X, \tau)$ if the strong $a$-level sets $A^{(a)}$ are closed in $i_{\tau}(\tau)$ for each $a \in P(L)$. The complement of a pseudo closed fuzzy set will be referred to as a pseudo open fuzzy set. The smallest pseudo closed fuzzy set containing $A$ is called the pseudo closure of $A$ and it is denoted by $\bar{A}^{ps}$.

**Definition 2.9** ([9]): A fuzzy set $\mu$ in a $L$-topological space $(X, \tau)$ is said to be starplus-compact if $\mu^{(a)}$ is compact in $(X, i_{\tau}(\tau))$ for each $a \in I_1$. The $L$-topological space $(X, \tau)$ is said to be starplus-compact if $(X, i_{\tau}(\tau))$ is compact for each $a \in I_1$, where $I_1 = [0, 1)$.

**Proposition 2.1** ([9]): Fuzzy continuous image of a starplus-compact fuzzy set is starplus-compact.

**Theorem 2.1** ([9]): Let $\{(X_j, \tau_j)\}_{j \in J}$ be a family of $L$-topological spaces. Then the product $L$-topological space $(\prod_{j \in J}X_j, \prod_{j \in J} \tau_j)$ is starplus-compact if and only if each $L$-topological space $(X_j, \tau_j), j \in J$ is starplus-compact.

**Theorem 2.2** ([9]): Let $K_j$ be a fuzzy set in the $L$-topological space $(X_j, \tau_j)$, $j = 1, 2, \ldots, n$. Then $\prod_{j=1}^n K_j$ is starplus-compact in $\prod_{j=1}^n X_j$ if and only if each $K_j$ is starplus-compact.
3. Local Starplus-Compactness

In this section we introduce the notion of local starplus-compactness, which is an extension of the notion of local compactness to the \(L\)-fuzzy setting. We extend the notion of starplus-compactness defined in [9] to the \(L\)-fuzzy setting as follows:

**Definition 3.1:** An \(L\)-set \(A\) in an \(L\)-topological space \((X, \tau)\) is said to be starplus-compact if \(A^{(a)}\) is compact in \((X, i_a(\tau))\) for each \(a \in P(L)\). The \(L\)-topological space \((X, \tau)\) is said to be starplus-compact if \((X, i_a(\tau))\) is compact for each \(a \in P(L)\).

**Definition 3.2:** An \(L\)-topological space \((X, \tau)\) is said to be locally starplus-compact if every \(L\)-fuzzy point in \(X\) has a starplus-compact neighbourhood in \(X\).

**Proposition 3.1:** Every discrete \(L\)-topological space is locally starplus-compact.

**Proof:** Since each fuzzy point \(x_a, a \in L\) is a starplus-compact open \(L\)-set and therefore a starplus-compact neighbourhood of \(x_a\).

**Proposition 3.2:** If \((X, \tau)\) is a locally starplus-compact \(L\)-topological space, then \((X, i_a(\tau))\) is locally compact for each \(a \in P(L)\).

**Proof:** Let \(x \in X\). Then \(x_1\) is a fuzzy point in \((X, \tau)\). Since it is locally starplus-compact, there exists a starplus-compact neighbourhood \(K\) of \(x_1\). Now \(x \in K^{(a)}\) for all \(a \in P(L)\) and \(K^{(a)}\) is compact in \(i_a(\tau)\). Since \(K\) is a neighbourhood of \(x_1\), there exists an open \(L\)-set \(U\) such that \(x_1 \in U \subset K\) which in turn implies that \(x \in U^{(a)} \subset K^{(a)}\) for all \(a \in P(L)\) and \(U^{(a)}\) is open in \(i_a(\tau)\). This completes the proof that \((X, i_a(\tau))\) is locally compact for each \(a \in P(L)\).

**Remark 3.1:** Converse of Proposition 3.2 is not true as is shown by the following Example.

**Example 3.1:** Let \(X = \mathbb{R}^n, n \geq 1\) and let \(T\) be the Euclidean topology on \(X\). Let \(L = \{(0, 0), 1 = (1, 1)\} \cup \{(x, y) : 0 < x < 1, 0 < y < 1\}\). Define \(\leq\) and the involution map \(\vee'\) on \(L\) as \((a, b) \leq (c, d)\) if and only if \(a \leq c, c \leq d\) and \((a, b)' = (1 - a, 1 - b)\), respectively. Also, \(\vee(a_i, b_i) = (\vee a_i, \vee b_i), \wedge(a_i, b_i) = (\wedge a_i, \wedge b_i)\). Then \((L, \leq, \vee, \wedge, ')\) a continuous lattice with an order reversing involution \(\vee\).

Let \(\delta = \{\alpha \wedge \chi_U : U \in T\}\) and each \(\alpha \in \{(a, b) : 0 < a < (1/2), 0 < b < (1/2)\} \cup \{c : c \in L\}\). Let \(\tau\) be the \(L\)-topology on \(X\) generated by the collection \(\delta\).

Then,

\[
i_a(\tau) = \begin{cases} T, & \text{if } \alpha < \left(\frac{1}{2}, \frac{1}{2}\right) \\ \text{The indiscrete topology, if } \alpha \leq \left(\frac{1}{2}, \frac{1}{2}\right). \end{cases}
\]

Hence \((X, i_a(\tau))\) is locally compact for each \(a \in P(L)\). However, \((X, \tau)\) is not locally starplus-compact, since no fuzzy point \(x_{\alpha}, \alpha \leq \left(\frac{1}{2}, \frac{1}{2}\right)\) has a starplus-compact neighbourhood in \((X, \tau)\).
Theorem 3.1: Let \((X, T)\) be a topological space. Then the following hold:

(i) The \(L\)-topological space \((X, \omega_L(T))\) is locally starplus-compact if and only if \((X, T)\) is locally compact.

(ii) The \(L\)-topological space \((X, \chi(T))\) is locally starplus-compact if and only if \((X, T)\) is locally compact.

Proof: (i) Suppose \((X, \omega_L(T))\) is locally starplus-compact. Since \(i_a(\omega_L(T)) = T\) by Proposition 3.2, it follows that the space \((X, T)\) is locally compact. Conversely, let \((X, T)\) be locally compact and let \(x_a\) be an \(L\)-fuzzy point in \(X\). Then there exists a compact neighbourhood \(C\) of \(x\) in \((X, T)\). So \(\chi_C\) is a starplus-compact neighbourhood of \(x_a\) in \((X, \omega_L(T))\). □

(ii) Proof of (ii) is similar to that of part (i). Hence, the theorem is proved.

Remark 3.2: The above theorem shows that the notion of local starplus-compactness is a good extension.

Remark 3.3: Every starplus-compact \(L\)-topological space is locally starplus-compact. However, the converse is not true as is exhibited by the following example.

Example 3.2: Let \(\mathbb{R}\) be the set of real numbers with the Euclidean topology \(T\). Since, \((\mathbb{R}, T)\) is locally compact, the \(L\)-topological space \((\mathbb{R}, \omega_L(T))\) is locally starplus-compact. However, \((\mathbb{R}, \omega_L(T))\) is not starplus-compact.

Proposition 3.3: A Hausdorff \(L\)-topological space is locally starplus-compact if and only if every neighbourhood of each fuzzy point contains a neighbourhood whose pseudo closure is starplus-compact.

Proof: Let \(X\) be a Hausdorff starplus-compact \(L\)-topological space and let \(K\) be a starplus-compact neighbourhood of an \(L\)-fuzzy point \(x_a\). If \(U\) is any neighbourhood of \(x_a\), then for each \(a \in P(L)\), \((U \land K)^{(a)} = U^{(a)} \cap K^{(a)} \subset K^{(a)}\) which in turn implies that \((U \land K)^{(a)} \subset \overline{K^{(a)}} = K^{(a)}\), since \((X, i_a(\tau))\) is Hausdorff for each \(a \in P(L)\). Hence \(((U \land K)^{(a)})_{ps} \subset K\). Proof of the converse is obvious. □

Proposition 3.4: A closed crisp \(L\)-subspace of a locally starplus-compact space is locally starplus-compact.

Proof: Let \(F \subset X\) be a crisp subset of \(X\) such that \(\chi_F\) is a closed \(L\)-set in \((X, \tau)\). Let \(x_a\) be an \(L\)-fuzzy point in \((F, \tau_F)\). Since \(X\) is locally starplus-compact, there exist a starplus-compact neighbourhood \(K\) of \(x_a\) in \(X\). Now, since \(\chi_F\) is closed in \((X, \tau)\), \(F\) is closed in \((X, i_a(\tau))\) for each \(a \in P(L)\) and so, \((K \land \chi_F)^{(a)} = K^{(a)} \cap F\) is compact in \((F, i_a(\tau_F))\) for each \(a \in P(L)\). Hence \(K \land \chi_F\) is a starplus-compact neighbourhood of \(x_a\) in \((F, \tau_F)\). □

Remark 3.4: The above Proposition shows that local starplus-compactness is closed hereditary. However, it is not hereditary as is reflected in the following example.
Example 3.3: Let $\mathbb{R}$ be the set of real numbers with the Euclidean topology $T$ and $\mathbb{Q}$ be the set of rational numbers with the subspace topology $T_\mathbb{Q}$. Then $(\mathbb{R}, T)$ is locally compact while $(\mathbb{Q}, T_\mathbb{Q})$ is not. Consider the $L$-topology $(\mathbb{R}, \omega_L(T))$, which is locally starplus-compact. We shall show that the $L$-subspace $(\mathbb{Q}, T_\mathbb{Q})$ is not locally starplus-compact. Now, $U \in T_\mathbb{Q}$ if and only if there exist a $V \in \omega_L(T)$ such that $U = V \land 1_\mathbb{Q}$. Hence, for each $a \in P(L)$

$$i_a(T_\mathbb{Q}) = \{U(a) : U \in T_\mathbb{Q}\}$$

$$= \{(V \land 1_\mathbb{Q})(a) : V \in \omega(T)\}$$

$$= \{V(a) \cap \mathbb{Q} : V(a) \in i_a(\omega(T)) = T\}$$

$$= \{A \cap \mathbb{Q} : A \in T\}$$

$$= T_\mathbb{Q}.$$  

Thus $i_a(T_\mathbb{Q}) = T_\mathbb{Q}$, for each $a \in P(L)$ and $(\mathbb{Q}, T_\mathbb{Q})$ is not locally compact. Hence $(\mathbb{Q}, T_\mathbb{Q})$ is not locally starplus-compact.

Proposition 3.5: An $L$-continuous open image of a locally starplus-compact $L$-topological space is locally starplus-compact.

Proof: Let $f : (X, \tau) \to (Y, \varsigma)$ be an $L$-continuous open map from a locally starplus-compact $L$-topology $(X, \tau)$ onto an $L$-topology $(Y, \varsigma)$. Let $y_a$ be a fuzzy point in $Y$. Then there exist a fuzzy point $x_a$ in $X$ such that $f(x_a) = y_a$. Since $X$ is locally starplus-compact, there exists a starplus-compact neighbourhood $K$ of $x_a$. Since $f$ is fuzzy continuous open map, by Proposition 2.1, $f(K)$ is a starplus-compact neighbourhood of the fuzzy point $y_a$ in $Y$. □

Remark 3.5: Fuzzy continuous image of a locally starplus-compact $L$-topological space need not be locally starplus-compact as is shown by the following Example.

Example 3.4: Let $X = \mathbb{R}^n, n \geq 1$ and let $T$ be the Euclidean topology on $X$. Then the $L$-topological space $(X, \omega_L(T))$ is locally starplus-compact. Let $Y = X$ and let $(Y, \tau)$ be the $L$-topological space as defined in Example 3.1. Then the identity map $i : (X, \omega_L(T)) \to (Y, \tau)$ is a fuzzy continuous surjection. Now the $L$-topological space $(X, \omega_L(T))$ is locally starplus-compact while $(Y, \tau)$ is not as shown in Example 3.1.

Proposition 3.5: A finite product of locally starplus-compact $L$-topological spaces is locally starplus-compact.

Proof: Let $\{(X_j, \tau_j) : j = 1, 2, \ldots, n\}$ be a finite collection of locally starplus-compact $L$-topological spaces and let $x_a = (x_1, x_2, \ldots, x_n)_a$ be a fuzzy point in the product $L$-topological space $(\prod_{j=1}^n X_j, \prod_{j=1}^n \tau_j)$. Then $(x_j)_a$ is a fuzzy point in the $L$-topological space $X_j$ and since $X_j$ is locally starplus-compact, there exist a starplus-compact neighbourhood $K_j, j = 1, 2, \ldots, n$ of $(x_j)_a$. By Theorem 2.2, $\prod_{j=1}^n K_j$ is a starplus-compact neighbourhood of $x_a$. Hence $\prod_{j=1}^n X_j$ is locally starplus-compact. □

Theorem 3.2: Let $\{(X_j, \tau_j) : j \in J\}$ be a collection of laminated $L$-topological spaces. The product $L$-topological space $\prod_{j \in J} X_j$ is locally starplus-compact if and only if each $X_j$ is starplus-compact except for finitely many, which are locally starplus-compact.
Proof: Suppose $X = \prod_{j \in J} X_j$ is locally starplus-compact. Since each $X_j$ is a laminated $L$-topological space, then for each $j \in J$, the projection map $\pi_j : X \to X_j$ is fuzzy continuous open surjection. So by Proposition 3.5, $X_j$ is locally starplus-compact. Again, for each $L$-fuzzy point $x_0 \in X$, there exist a starplus-compact neighbourhood $K$ of $x_0$. Then each $\pi_j(K)$ is starplus-compact and since $\pi_j(K) = X_j$ for all $j$ except for finitely many, the result follows.

Conversely, suppose that all the $X_j$’s are starplus-compact except for a finitely many, which are locally starplus-compact, say $X_{j_1}, X_{j_2}, \ldots, X_{j_n}$. Then $Y = \prod_{j \in J \setminus \{j_1, j_2, \ldots, j_n\}} X_j$ is starplus-compact by Theorem 2.1, and so it is locally starplus-compact. Now, the product $\prod_{i=1}^n X_{j_i}$ is locally starplus-compact by Proposition 3.6, and hence $Y \times \prod_{i=1}^n X_{j_i}$ is locally starplus-compact by Proposition 3.6 and the same is homeomorphic to the product $L$-topological space $X$.

Remark 3.6: The following example shows that local starplus-compactness is neither expansive nor contractive.

Example 3.5: Let $X = \mathbb{R}^n, n \geq 1$ with the Euclidean topology $T$. Consider the fuzzy topologies $\omega_L(T), \tau$ and $\tau_0$ on $X$, where $\tau$ is the fuzzy topology defined on $X$ in Example 3.1 and $\tau_0$ be the indiscrete fuzzy topology. Then $\tau_0 \subset \tau \subset \omega(T)$ and the $L$-topological space $(X, \omega_L(T))$ and $(X, \tau_0)$ are locally starplus-compact whereas the $L$-topological space $(X, \tau)$ is not. This shows that the notion of locally starplus-compactness is neither expansive nor contractive.

4. Conclusion

The notion of local starplus-compactness is introduced, which is the extension of the notion of local compactness in general topology to the $L$-fuzzy setting. On studying its basic properties, it turns out that the category of local starplus-compact fuzzy topological spaces is finitely productive, closed hereditary and that local starplus-compactness is a good extension of the notion of local compactness in general topology. It is shown that the class of locally starplus-compact fuzzy topologies is invariant under $L$-continuous open surjections.

Disclosure statement

No potential conflict of interest was reported by the author.

Notes on contributor

Dr A. R. Prasannan is an Associate Professor in the Department of Mathematics, Maharaja Agrasen College, University of Delhi, India. He received his PhD degree in Fuzzy Uniformities and Fuzzy Topologies on Function Spaces from the University of Delhi. His research areas are General Topology, Function Spaces and Fuzzy Topology. He has published many research articles in reputed international journals. He was the supervisor of many PhD scholars.

ORCID

A. R. Prasannan http://orcid.org/0000-0003-0533-8417
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