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Operation approaches on decompositions of $\gamma-$continuous function

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Abstract

In this paper, we introduce the notions of $\alpha^{*}-\gamma-set$, $t-\gamma-set$, $s-\gamma-set$, $\beta^{*}-\gamma-set$, $C_{\gamma}-continuity$, $B_{\gamma}-continuity$, $S_{\gamma}-continuity$ and $\beta_{\gamma}-continuity$. Thus we have decompositions of $\gamma-continuity$.

Keywords

$\alpha-\gamma-open$, $semi-\gamma-open$, $pre-\gamma-open$, $\beta-\gamma-open$.

AMS Subject Classification

54A05, 54C08.

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Contents

1. Introduction

In [13], Kasahara unified several known characterizations of compactness, nearly compact spaces and H-closed spaces by introducing a certain operation on a topology. By using operation Jankovic [14] investigated functions with closed graphs. Ogata [7] defined the concept of $\gamma-open$ sets with an operation γ in the manner of Kasahara [13] and introduced some new separation axioms of topological spaces. In [11], the authors introduced and investigated the notions of $\alpha-\gamma-open$ sets. In [5, 6] the authors introduced and investigated the notions of $semi-\gamma-open$ set, $pre-\gamma-open$ set and $\beta-\gamma-open$ set. A decomposition of $\gamma-$continuity is a pair of properties of functions between topological spaces with an operation γ each of which is weaker than $\gamma-$continuity, and which are together equivalent to $\gamma-$continuity. One member of the pair is a $\gamma-$continuity dual of the other. In this paper, we introduce the notions of $\alpha^{*}-\gamma-set$, $t-\gamma-set$, $s-\gamma-set$, $\beta-\gamma-set$, $C_{\gamma}-continuity$, $B_{\gamma}-continuity$, $S_{\gamma}-continuity$, $\beta_{\gamma}-continuity$. Thus we have decompositions of $\gamma-continuity$.

2. Preliminaries

Let (X,τ) be a topological space. Let γ be an operation on τ, that is, γ is a function from τ into the power set $\wp(X)$ of X such that $V\subset\gamma(V)$ for any $V\in\tau$ where $\gamma(V)$ denotes the value of γ at V. This operation denoted by $\gamma:\tau\rightarrow\wp(X)$. Let us take a topological space (X,τ) and $W\subset X$ with an operation γ on τ. Then W is called $\gamma-open$ [7] if for each $x\in W$, there exists an open neighbourhood U of x such that $\gamma(U)\subset W$. The empty set ϕ is $\gamma-$open for any operation $\gamma:\tau\rightarrow\wp(X)$. Let τ_{γ} be the collections of all $\gamma-open$ sets of (X,τ) with τ_{γ}. For any topological space (X,τ), $\tau_{\gamma}\subset\tau$ [7]. Complements of $\gamma-open$ sets are defined as $\gamma-closed$. The $\gamma-closure$ of $W\subset X$ with an operation γ is denoted by $Cl_{\gamma}(W)$, is defined as

$$Cl_{\gamma}(W)=\cap\{B: B \text{ is } \gamma-closed \text{ and } W\subset B\}.$$

The $\gamma-interior$ of $W\subset X$ with an operation γ on τ is denoted by $Int_{\gamma}(W)$, is defined as

$$Int_{\gamma}(W)=\cup\{B: B \text{ is a } \gamma-open \text{ set and } B\subset W\}.$$

A topological space X with an operation γ on τ is said to be $\gamma-regular$ if for each $x\in X$ and each neighbourhood V of x, there exists an open neighbourhood U of x with $\gamma(U)\subset V$. According to this notion, $\tau=\tau_{\gamma}\Leftrightarrow X$ is a $\gamma-regular$ space [7].

In this paper, (X,τ) and (Y,σ) denotes topological space. Furthermore, there is no separation axioms on them unless otherwise mentioned. $Cl(W)$ and $Int(W)$ denote the closure of W and the interior of W, respectively, in topological space (X,τ). Let us recall some of basic definitions.

Definition 2.1. *Let (X,τ) be a topological space and $W\subset X$. Then*
1. W is called an $\alpha-open\ set$ [12] if $W\subset Int(Cl(Int(W)))$,
2. W is called a $pre-open\ set$ [2] if $W\subset Int(Cl(W))$,
3. W is called a $semi-open\ set$ [10] if $W\subset Cl(Int(W))$,
4. W is called a $\beta-open\ set$ [9] if $W\subset Cl(Int(Cl(W)))$,
5. W is called an α^*-set [4] if $Int(Cl(Int(W)))=Int(W)$,
6. W is called a $C-set$ [4] if $W=U\cap V$, where $U\in\tau$ and V is an α^*-set,
7. W is called a $t-set$ [8] if $Int(Cl(W))=Int(W)$,
8. W is called a $B-set$ [8] if $W=U\cap V$, where $U\in\tau$ and V is a $t-set$,

Definition 2.2. *Let (X,τ) be a topological space and $W\subset X$ with an operation γ on τ. Then*
1. W is called an $\alpha-\gamma-open\ set$ [11] if $W\subset Int_\gamma(Cl_\gamma(Int_\gamma(W)))$,
2. W is called a $pre-\gamma-open\ set$ [6] if $W\subset Int_\gamma(Cl_\gamma(W))$,
3. W is called a $semi-\gamma-open\ set$ [5] if $W\subset Cl_\gamma(Int_\gamma(W))$,
4. W is called a $\beta-\gamma-open\ set$ [6] if $W\subset Cl_\gamma(Int_\gamma(Cl_\gamma(W)))$,
5. W is called a $\gamma-regular\ open\ set$ [1] if $Int_\gamma(Cl_\gamma(W))=W$.

Let (X,τ) be a topological space and γ be an operation on τ. The $\beta-\gamma-interior$ of $W\subset X$ with an operation γ is denoted by $\beta Int_\gamma(W)$ [3], is defined as

$\beta Int_\gamma(W)=\cap\{B: B \text{ is } \beta-\gamma-open \text{ and } B\subset W\}$. Complements of $\beta-\gamma-open$ sets are defined as $\beta-\gamma-closed$. Therefore, we have $\beta Int_\gamma(W)=W\cap Cl_\gamma(Int_\gamma(Cl_\gamma(W)))$.

Definition 2.3. *Let (X,τ) and (Y,σ) be two topological spaces and let $\gamma:\tau\longrightarrow\wp(X)$ be the operation on τ. A mapping $f:(X,\tau)\longrightarrow(Y,\sigma)$ is said to be $\gamma-continuous$ [3] (resp. $\alpha-\gamma-continuous$ [11], $pre-\gamma-continuous$ [6], $semi-\gamma-continuous$ [5], $\beta-\gamma-continuous$ [6]) if for each $x\in X$ and each open set V of Y containing $f(x)$, there exists a $\gamma-open$ set U containing x (resp. $\alpha-\gamma-open$ set, $pre-\gamma-open$ set, $semi-\gamma-open$ set, $\beta-\gamma-open$ set) such that $f(U)\subset V$.*

3. $C_\gamma-sets$, $B_\gamma-sets$, $S_\gamma-sets$ and $\beta_\gamma-sets$

Definition 3.1. *Let (X,τ) be a topological space and $W\subset X$ with an operation γ on τ. Then*
1. W is called an $\alpha^*-\gamma-set$ if $Int_\gamma(Cl_\gamma(Int_\gamma(W)))=Int_\gamma(W)$,
2. W is called a $t-\gamma-set$ if $Int_\gamma(Cl_\gamma(W))=Int_\gamma(W)$,
3. W is called a $s-\gamma-set$ if $Cl_\gamma(Int_\gamma(W))=Int_\gamma(W)$,
4. W is called a $\beta^*-\gamma-set$ if $Cl_\gamma(Int_\gamma(Cl_\gamma(W)))=Int_\gamma(W)$.

Proposition 3.2. *The following are equivalent for a subset W of a space (X,τ) with an operator γ,*
1. W is $\alpha^*-\gamma-set$,
2. W is $\beta-\gamma-closed$ set,
3. $Int_\gamma(W)$ is $\gamma-regular-open$ set.

Proof. Straightforward. □

Proposition 3.3. *Let W be a subset of a space (X,τ) with an operator γ,*
1. A $semi-\gamma-open$ set W is a $t-\gamma-set$ if and only if W is an $\alpha^*-\gamma-set$.
2. A is an $\alpha-\gamma-open$ set and W is $\alpha^*-\gamma-set$ if and only if W is $\gamma-regular-open$ set.

Proof. 1. Let W be a $semi-\gamma-open$ and W be an $\alpha^*-\gamma-set$. Since W is a $semi-\gamma-open$, $Cl_\gamma(Int_\gamma(W))=Cl_\gamma(W)$ and $Int_\gamma(Cl_\gamma(W))=Int_\gamma(Cl_\gamma(Int_\gamma(W)))=Int_\gamma(W)$. Therefore, W is a $t-\gamma-set$.
2. Let W be an $\alpha-\gamma-open$ set and W be an $\alpha^*-\gamma-set$. By Proposition 1 and the definition of $\alpha-\gamma-open$ set, we have $Int_\gamma(Cl_\gamma(W))=W$ and hence $Int_\gamma(Cl_\gamma(W))=Int_\gamma(Cl_\gamma(Int_\gamma(W)))=W$.
The converse is obvious. □

Definition 3.4. *Let (X,τ) be a topological space and $W\subset X$ with an operation γ on τ. Then*
1. W is called a $C_\gamma-set$ if $W=U\cap V$, where $U\in\tau_\gamma$ and V is an $\alpha^*-\gamma-set$,
2. W is called a $B_\gamma-set$ if $W=U\cap V$, where $U\in\tau_\gamma$ and V is a $t-\gamma-set$,
3. W is called a $S_\gamma-set$ if $W=U\cap V$, where $U\in\tau_\gamma$ and V is a $s-\gamma-set$,
4. W is called a $\beta_\gamma-set$ if $W=U\cap V$, where $U\in\tau_\gamma$ and V is a $\beta^*-\gamma-set$,
5. W is called a $\gamma-\gamma-\beta-open$ set [3] if $\beta Int_\gamma(W)=Int_\gamma(W)$.

Proposition 3.5. *Let (X,τ) be a topological space with an operation γ and $W\subset X$. Then the following hold:*
1. If W is a $t-\gamma-set$, then W is an $\alpha^*-\gamma-set$,
2. If W is a $s-\gamma-set$, then W is an $\alpha^*-\gamma-set$,
3. If W is a $\beta^*-\gamma-set$, then W is both $t-\gamma-set$ and $s-\gamma-set$.
4. $t-\gamma-set$ and $s-\gamma-set$ are independent.

Proof. Straightforward from the definitions of $\gamma-interior$ and $\gamma-closure$. □

Remark 3.6. *The converses are false. See the followig examples.*

Example 3.7. *Let $X=\{a,b,c\}$ and $\tau=\{\phi,X,\{a\},\{c\},\{a,c\},\{a,b\}\}$. We define an operator $\gamma:\tau\longrightarrow\wp(X)$ by $\gamma(W)=W\cup\{a,c\}$ if $W\neq\{a\}$ and $\gamma(W)=W$ if $W=\{a\}$. Then $\tau_\gamma=\{\phi,X,\{a\},\{c\},\{a,c\}\}$. If we take $W=\{a\}$, then W is an $\alpha^*-\gamma-set$ and a $t-\gamma-set$, but it is not a $s-\gamma-set$ and not a $\beta^*-\gamma-set$.*

Example 3.8. *Let $X=\{a,b,c\}$ and $\tau=\{\phi,X,\{a\},\{a,b\}\}$. We define an operator $\gamma:\tau\longrightarrow\wp(X)$ by $\gamma(W)=W$ if $W=\{a,c\}$ or $W=\phi$ and $\gamma(W)=X$ if otherwise. Then $\tau_\gamma=\{\phi,X\}$. If we take $W=\{b\}$, then W is an $\alpha^*-\gamma-set$ and a $s-\gamma-set$, but it is not a $t-\gamma-set$ and not a $\beta^*-\gamma-set$.*

Proposition 3.9. *Let (X,τ) be a topological space with an operation γ and $W \subset X$. Then the following hold:*
1. If W is an $\alpha^* - \gamma - set$, then W is $C_\gamma - set$,
2. If W is a $t - \gamma - set$, then W is $B_\gamma - set$,
3. If W is a $s - \gamma - set$, then W is $S_\gamma - set$,
4. If W is a $\beta^* - \gamma - set$, then W is $\beta_\gamma - set$.

Proof. 1. Let W be an $\alpha^* - \gamma - set$. If we take $U = X \in \tau_\gamma$, then $W = U \cap W$ and hence W is a $C_\gamma - set$.

The proof of (2), (3) and (4) are same. □

Remark 3.10. *The converses are false. See the following examples.*

Example 3.11. *In Example 1, if we take $W = \{a,c\}$, then W is a $C_\gamma - set$ (resp. $B_\gamma - set$, $S_\gamma - set$, $\beta_\gamma - set$), but it is not an $\alpha^* - \gamma - set$ (resp. $t - \gamma - set$, $s - \gamma - set$, $\beta^* - \gamma - set$).*

Proposition 3.12. *1. A $B_\gamma - set$ is a $C_\gamma - set$,*
2. A $S_\gamma - set$ is a $C_\gamma - set$,
3. A $\beta_\gamma - set$ is both a $B_\gamma - set$ and a $S_\gamma - set$.

Remark 3.13. *The converses are false. $B_\gamma - set$ and $S_\gamma - set$ are independent notions. See the following examples.*

Example 3.14. *In Example 1, if we take $W = \{a,b\}$, then W is a $B_\gamma - set$, but it is not a $S_\gamma - set$ and not a $\beta_\gamma - set$.*

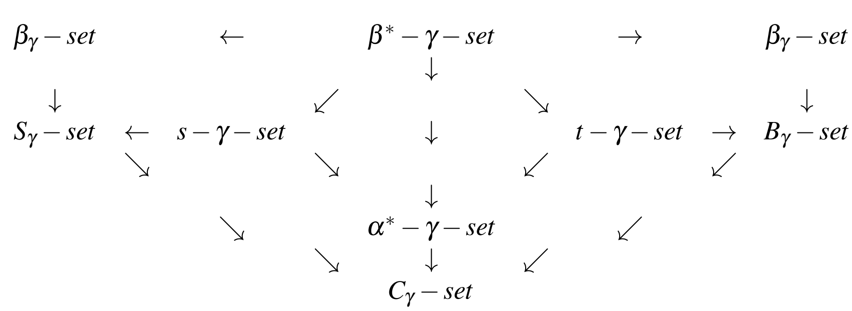
In Example 2, if we take $W = \{b\}$, then W is a $C_\gamma - set$ and a $S_\gamma - set$, but it is not a $B_\gamma - set$ and not a $\beta_\gamma - set$.

Proposition 3.15. *Let (X,τ) be a topological space with an operation γ and $W \subset X$. Then $\gamma - \gamma - \beta - open$ set [3] and $\beta_\gamma - set$ are equivalent.*

Proof. Let W be a $\beta^* - \gamma - set$. Then $Cl_\gamma(Int_\gamma(Cl_\gamma(W))) = Int_\gamma(W)$. Hence by Proposition 4(4), W is $\beta_\gamma - set$. Therefore, $\beta Int_\gamma(W) = W \cap Cl_\gamma(Int_\gamma(Cl_\gamma(W))) = W \cap Int_\gamma(W) = Int_\gamma(W)$. Thus W is $\gamma - \gamma - \beta - open$ set.

Conversely, let W be a $\gamma - \gamma - \beta - open$ set. Then $\beta Int_\gamma(W) = Int_\gamma(W)$. Hence $\beta Int_\gamma(W)$ is a $\gamma - open$ set. Since $W = W \cap X$, W is $\beta_\gamma - set$. □

Remark 3.16. *We have the following diagram according to sets defined above. It is shown in Examples 1-2 that the notion of $S_\gamma - sets$ is different from that of $B_\gamma - sets$.*



Theorem 3.17. *For a subset W of a space (X,τ) with an operation γ, the following properties are equivalent:*
1. W is $\gamma - open$,
2. W is an $\alpha - \gamma - open$ set and a $C_\gamma - set$,
3. W is a $pre - \gamma - open$ set and a $B_\gamma - set$,
4. W is a $semi - \gamma - open$ set and a $S_\gamma - set$,
5. W is a $\beta - \gamma - open$ set and a $\beta_\gamma - set$.

Proof. The proof of (1)⇒(2), (1)⇒(3), (1)⇒ (4), (1)⇒(5) are obvious.

(5)⇒(1) Let W be a $\beta - \gamma - open$ set and a $\beta_\gamma - set$. Since W is a $\beta_\gamma - set$, we have $W = U \cap V$, where U is a $\gamma - open$ set and V is a $\beta^* - \gamma - set$. By the hypothesis, W is also $\beta - \gamma - open$ and we have

$$\begin{aligned} W &\subset Cl_\gamma(Int_\gamma(Cl_\gamma(W))) = Cl_\gamma(Int_\gamma(Cl_\gamma(U \cap V))) \\ &\subset Cl_\gamma(Int_\gamma(Cl_\gamma(U) \cap Cl_\gamma(V))) \\ &= Cl_\gamma(Int_\gamma(Cl_\gamma(U)) \cap Int_\gamma(Cl_\gamma(V))) \\ &\subset Cl_\gamma(Int_\gamma(Cl_\gamma(U))) \cap Cl_\gamma(Int_\gamma(Cl_\gamma(V))) \\ &\subset Cl_\gamma(Int_\gamma(Cl_\gamma(U))) \cap Int_\gamma(V). \end{aligned}$$

Hence

$$\begin{aligned} W &= U \cap V = (U \cap V) \cap U \\ &\subset (Cl_\gamma(Int_\gamma(Cl_\gamma(U))) \cap Int_\gamma(V)) \cap U \\ &= (Cl_\gamma(Int_\gamma(Cl_\gamma(U))) \cap U) \cap Int_\gamma(V). \end{aligned}$$

Notice $W = U \cap V \supset U \cap Int_\gamma(V)$. Therefore, we obtain $W = U \cap Int_\gamma(V)$.

(2)⇒(1), (3)⇒(1), (4)⇒(1) are shown similarly. □

Remark 3.18. *If (X,τ) is a $\gamma - regular$ space, then the concept of $\alpha - \gamma - open$ and $\alpha - open$ (resp. $pre - \gamma - open$ and $pre - open$, $semi - \gamma - open$ and $semi - open$, $\beta - \gamma - open$ and $\beta - open$, $B\gamma - set$ and $B - set$, $C\gamma - set$ and $C - set$) coincide.*

4. Decompositions of $\gamma - continuity$

Definition 4.1. *Let $f : (X,\tau) \longrightarrow (Y,\sigma)$ be a function and let $\gamma : \tau \longrightarrow \wp(X)$ be the operation on τ. If for each $V \in \sigma$, $f^{-1}(V)$ is a $C_\gamma - set$ (resp. $B_\gamma - set$, $S_\gamma - set$, $\beta_\gamma - set$), then f is said to be $C_\gamma - continuous$ (resp. $B_\gamma - continuous$, $S_\gamma - continuous$, $\beta_\gamma - continuous$).*

By Proposition 5, we get the following proposition.

Proposition 4.2. *1. A $B_\gamma - continuous$ function is $C_\gamma - continuous$,*
2. A $S_\gamma - continuous$ function is $C_\gamma - continuous$,
3. A $\beta_\gamma - continuous$ is both $B_\gamma - continuous$ and $S_\gamma - continuous$.

Theorem 4.3. *For a function $f:(X,\tau)\longrightarrow(Y,\sigma)$ with the operation γ on τ, the following properties are equivalent:*
1. f is $\gamma-continuous$
2. f is $\alpha-\gamma-$ continuous and $C_\gamma-$ continuous,
3. f is $pre-\gamma-$ continuous and $B_\gamma-$ continuous,.
4. f is $semi-\gamma-$ continuous and $S_\gamma-$ continuous,
5. f is $\beta-\gamma-$ continuous and $\beta_\gamma-$ continuous.

Proof. This is an immediate consequence of Theorem 1. □

Remark 4.4. *$\alpha-\gamma-$ continuity and $C_\gamma-$ continuity, $pre-\gamma-$ continuity and $B_\gamma-$ continuity, $semi-\gamma-$ continuity and $S_\gamma-$ continuity, $\beta-\gamma-$ continuity and $\beta_\gamma-$ continuity are independent of each other. See the following examples.*

Example 4.5. *Let $X=Y=\{a,b,c\}$ and $\tau=\{\phi,X,\{a\},\{c\},\{a,c\},\{a,b\}\}$ and $\sigma=\{\phi,Y,\{a\},\{c\},\{a,c\}\}$. We define an operator $\gamma:\tau\longrightarrow\wp(X)$ by $\gamma(W)=W\cup\{a,c\}$ if $W\neq\{a\}$ and $\gamma(W)=W$ if $W=\{a\}$. Then $\tau_\gamma=\{\phi,X,\{a\},\{c\},\{a,c\}\}$. Define a function $f:(X,\tau)\longrightarrow(Y,\sigma)$ as $f(a)=f(b)=a$, $f(c)=c$. Then f is $C_\gamma-$ continuous (resp. $B_\gamma-$ continuous, $semi-\gamma-$ continuous and $\beta-\gamma-$ continuous), but it is not $\alpha-\gamma-$ continuous (resp. $pre-\gamma-$ continuous, $S_\gamma-$ continuous and $\beta_\gamma-$ continuous).*

Example 4.6. *Let $X=Y=\{a,b,c\}$ and $\tau=\{\phi,X,\{a\},\{a,b\}\}$ and $\sigma=\{\phi,Y,\{a\},\{b\},\{a,b\}\}$. We define an operator $\gamma:\tau\longrightarrow\wp(X)$ by $\gamma(W)=W$ if $W=\{a,c\}$ or $W=\phi$ and $\gamma(W)=X$ if otherwise. Then $\tau_\gamma=\{\phi,X\}$. Define a function $f:(X,\tau)\longrightarrow(Y,\sigma)$ as $f(a)=f(c)=a$, $f(b)=b$. Then f is both $S_\gamma-$ continuous and $pre-\gamma-$ continuous, but it is neither $semi-\gamma-$ continuous nor $B_\gamma-$ continuous.*

Example 4.7. *Let $X=Y=\{a,b,c,d\}$ and $\tau=\{\phi,X,\{a\},\{b\},\{c\},\{a,b\},\{a,c\},\{b,c\},\{a,b,c\},\{a,b,d\}\}$ and $\sigma=\{\phi,Y,\{a\},\{b\},\{a,b\}\}$. We define an operator $\gamma:\tau\longrightarrow\wp(X)$ by $\gamma(W)=Cl(W)$ if $W\neq\{a\}$ and $\gamma(W)=Int(Cl(W))$ if $W=\{a\}$. Then $\tau_\gamma=\{\phi,\{a\},\{c\},\{a,c\},\{a,b,d\},X\}$. Define a function $f:(X,\tau)\longrightarrow(Y,\sigma)$ as $f(a)=f(c)=a$, $f(b)=f(d)=b$. Then f is $\beta_\gamma-$ continuous, but it is not $\beta-\gamma-$ continuous.*

Example 4.8. *Let $X=Y=\{a,b,c\}$ and $\tau=\{\phi,X,\{a\},\{c\},\{a,c\},\{b,c\}\}$ and $\sigma=\{\phi,Y,\{a\}\}$. We define an operator $\gamma:\tau\longrightarrow\wp(X)$ by $\gamma(W)=Int(Cl(W))$ if $W=\{a\}$ and $\gamma(W)=X$ if $W\neq\{a\}$. Then $\tau_\gamma=\{\phi,\{a\},X\}$. Define a function $f:(X,\tau)\longrightarrow(Y,\sigma)$ as $f(a)=f(c)=a$, $f(b)=b$. Then f is $\alpha-\gamma-$ continuous, but it is not $C_\gamma-$ continuous.*

Corollary 4.9. *Let (X,τ) be a $\gamma-regular$ space. For a function $f:(X,\tau)\longrightarrow(Y,\sigma)$, the following properties are equivalent:*
1. f is continuous,
2. f is $pre-$ continuous and $B-$ continuous [8],
3. f is $\alpha-$ continuous and $C-$ continuous [4].

Proof. In $\gamma-regular$ space, we have $\tau=\tau_\gamma$. □

5. Conclusion

A decomposition of $\gamma-$continuity is a pair of properties of functions between topological spaces with an operation γ each of which is weaker than $\gamma-$continuity, and which are together equivalent to $\gamma-$continuity. One member of the pair is a $\gamma-$continuity dual of the other. In this paper, we have obtain decompositions of $\gamma-continuity$.

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