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# The Line $n$-sigraph of a Symmetric $n$-sigraph-V

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Abstract. An *n-tuple* $(a_1, a_2, ..., a_n)$ is *symmetric*, if $a_k = a_{n-k+1}, 1 \leq k \leq n$. Let $H_n = \{(a_1, a_2, ..., a_n) : a_k \in \{+, -\}, a_k = a_{n-k+1}, 1 \leq k \leq n\}$ be the set of all symmetric $n$-tuples. A *symmetric n-sigraph (symmetric n-marked graph)* is an ordered pair $S_n = (G, \sigma)$ ($S_n = (G, \mu)$), where $G = (V, E)$ is a graph called the *underlying graph* of $S_n$ and $\sigma : E \to H_n$ ($\mu : V \to H_n$) is a function. The *restricted super line graph of index* $r$ of a graph $G$, denoted by $\mathcal{RL}_r(G)$. The vertices of $\mathcal{RL}_r(G)$ are the $r$-subsets of $E(G)$ and two vertices $P = \{p_1, p_2, ..., p_r\}$ and $Q = \{q_1, q_2, ..., q_r\}$ are adjacent if there exists exactly one pair of edges, say $p_i$ and $q_j$, where $1 \leq i, j \leq r$, that are adjacent edges in $G$. Analogously, one can define the *restricted super line symmetric n-sigraph of index r* of a symmetric $n$-sigraph $S_n = (G, \sigma)$ as a symmetric $n$-sigraph $\mathcal{RL}_r(S_n) = (\mathcal{RL}_r(G), \sigma')$, where $\mathcal{RL}_r(G)$ is the underlying graph of $\mathcal{RL}_r(S_n)$, where for any edge $PQ$ in $\mathcal{RL}_r(S_n)$, $\sigma'(PQ) = \sigma(P)\sigma(Q)$. It is shown that for any symmetric $n$-sigraph $S_n$, its $\mathcal{RL}_r(S_n)$ is $i$-balanced and we offer a structural characterization of super line symmetric $n$-sigraphs of index $r$. Further, we characterize symmetric $n$-sigraphs $S_n$ for which $\mathcal{RL}_r(S_n) \sim \mathcal{L}_r(S_n)$ and $\mathcal{RL}_r(S_n) \cong \mathcal{L}_r(S_n)$, where $\sim$ and $\cong$ denotes switching equivalence and isomorphism and $\mathcal{RL}_r(S_n)$ and $\mathcal{L}_r(S_n)$ are denotes the restricted super line symmetric $n$-sigraph of index $r$ and super line symmetric $n$-sigraph of index $r$ of $S_n$ respectively.

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## 1. Introduction

Unless mentioned or defined otherwise, for all terminology and notion in graph theory the reader is refer to [2]. We consider only finite, simple graphs free from self-loops.

Let $n \geq 1$ be an integer. An *n-tuple* $(a_1, a_2, ..., a_n)$ is *symmetric*, if $a_k = a_{n-k+1}, 1 \leq k \leq n$. Let $H_n = \{(a_1, a_2, ..., a_n) : a_k \in \{+, -\}, a_k = a_{n-k+1}, 1 \leq k \leq n\}$ be the set of all symmetric $n$-tuples. Note that $H_n$ is a group under coordinate wise multiplication, and the order of $H_n$ is $2^m$, where $m = \lceil \frac{n}{2} \rceil$.

A *symmetric n-sigraph (symmetric n-marked graph)* is an ordered pair $S_n = (G, \sigma)$ ($S_n = (G, \mu)$), where $G = (V, E)$ is a graph called the *underlying graph* of $S_n$ and $\sigma : E \to H_n$ ($\mu : V \to H_n$) is a function.

In this paper by an *n-tuple/n-sigraph/n-marked graph* we always mean a symmetric $n$-tuple/symmetric $n$-sigraph/symmetric $n$-marked graph.

An $n$-tuple $(a_1, a_2, ..., a_n)$ is the *identity n-tuple*, if $a_k = +$, for $1 \leq k \leq n$, otherwise it is a *non-identity n-tuple*. In an $n$-sigraph $S_n = (G, \sigma)$ an edge labelled with the identity $n$-tuple is called an *identity edge*, otherwise it is a *non-identity edge*.

Further, in an $n$-sigraph $S_n = (G, \sigma)$, for any $A \subseteq E(G)$ the *n-tuple* $\sigma(A)$ is the product of the $n$-tuples on the edges of $A$.

In [17], the authors defined two notions of balance in $n$-sigraph $S_n = (G, \sigma)$ as follows (See also R. Rangarajan and P.S.K.Reddy [6]):

**Definition 1.1.** Let $S_n = (G, \sigma)$ be an $n$-sigraph. Then,
(i) $S_n$ is *identity balanced* (or *i-balanced*), if product of $n$-tuples on each cycle of $S_n$ is the identity $n$-tuple, and
(ii) $S_n$ is *balanced*, if every cycle in $S_n$ contains an even number of non-identity edges.
**Note:** An $i$-balanced $n$-sigraph need not be balanced and conversely.
The following characterization of $i$-balanced $n$-sigraphs is obtained in [17].

**Proposition 1.1.** (**E. Sampathkumar et al. [17]**)
*An n-sigraph $S_n = (G, \sigma)$ is i-balanced if, and only if, it is possible to assign n-tuples to its vertices such that the n-tuple of each edge uv is equal to the product of the n-tuples of u and v.*

Let $S_n = (G, \sigma)$ be an $n$-sigraph. Consider the $n$-marking $\mu$ on vertices of $S_n$ defined as follows: each vertex $v \in V$, $\mu(v)$ is the $n$-tuple which is the product of the $n$-tuples on the edges incident with $v$. *Complement* of $S_n$ is an $n$-sigraph

$\overline{S_n} = (\overline{G}, \sigma^c)$, where for any edge $e = uv \in \overline{G}$, $\sigma^c(uv) = \mu(u)\mu(v)$. Clearly, $\overline{S_n}$ as defined here is an $i$-balanced $n$-sigraph due to Proposition 1.1 [9].

In [17], the authors also have defined switching and cycle isomorphism of an $n$-sigraph $S_n = (G, \sigma)$ as follows: (See also [3, 7, 8] & [9]-[16])

Let $S_n = (G, \sigma)$ and $S'_n = (G', \sigma')$, be two $n$-sigraphs. Then $S_n$ and $S'_n$ are said to be *isomorphic*, if there exists an isomorphism $\phi : G \to G'$ such that if $uv$ is an edge in $S_n$ with label $(a_1, a_2, ..., a_n)$ then $\phi(u)\phi(v)$ is an edge in $S'_n$ with label $(a_1, a_2, ..., a_n)$.

Given an $n$-marking $\mu$ of an $n$-sigraph $S_n = (G, \sigma)$, *switching* $S_n$ with respect to $\mu$ is the operation of changing the $n$-tuple of every edge $uv$ of $S_n$ by $\mu(u)\sigma(uv)\mu(v)$. The $n$-sigraph obtained in this way is denoted by $\mathcal{S}_\mu(S_n)$ and is called the *$\mu$-switched $n$-sigraph* or just *switched $n$-sigraph*.

Further, an $n$-sigraph $S_n$ *switches* to $n$-sigraph $S'_n$ (or that they are *switching equivalent* to each other), written as $S_n \sim S'_n$, whenever there exists an $n$-marking of $S_n$ such that $\mathcal{S}_\mu(S_n) \cong S'_n$.

Two $n$-sigraphs $S_n = (G, \sigma)$ and $S'_n = (G', \sigma')$ are said to be *cycle isomorphic*, if there exists an isomorphism $\phi : G \to G'$ such that the $n$-tuple $\sigma(C)$ of every cycle $C$ in $S_n$ equals to the $n$-tuple $\sigma(\phi(C))$ in $S'_n$. We make use of the following known result (see [17]).

**Proposition 1.2.(E. Sampathkumar et al. [17])**
*Given a graph $G$, any two $n$-sigraphs with $G$ as underlying graph are switching equivalent if, and only if, they are cycle isomorphic.*

In this paper, we introduced the notion called restricted super line $n$-sigraph of index $r$ and we obtained some interesting results in the following sections. The restricted super line $n$-sigraph of index $r$ is the generalization of line $n$-sigraph.

## 2. Restricted Super Line $n$-sigraph $\mathcal{L}_r(S_n)$

In [4], K. Manjula introduced the concept of the *restricted super line graph*, which generalizes the notion of line graph. For a given $G$, its restricted super line graph $\mathcal{RL}_r(G)$ of index $r$ is the graph whose vertices are the $r$-subsets of $E(G)$, and two vertices $P = \{p_1, p_2, ..., p_r\}$ and $Q = \{q_1, q_2, ..., q_r\}$ are adjacent if there exists exactly one pair of edges, say $p_i$ and $q_j$, where $1 \leq i, j \leq r$, that are adjacent edges in $G$. In [1], the authors introduced the concept of the *super line graph* as follows: For a given $G$, its super line graph $\mathcal{L}_r(G)$ of index $r$ is the graph whose vertices are the $r$-subsets of $E(G)$, and two vertices $P$ and $Q$ are adjacent if there exist $p \in P$

and $q \in Q$ such that $p$ and $q$ are adjacent edges in $G$. Clearly $\mathcal{RL}_r(G)$ is a spanning subgraph of $\mathcal{L}_r(G)$. From the definitions of $\mathcal{RL}_r(G)$ and $\mathcal{L}_r(G)$, it turns out that $\mathcal{RL}_1(G)$ and $\mathcal{L}_1(G)$ coincides with the line graph $L(G)$.

In this paper, we extend the notion of $\mathcal{RL}_r(G)$ to realm of $n$-sigraphs as follows: The *restricted super line $n$-sigraph of index $r$* of an $n$-sigraph $S_n = (G, \sigma)$ as an $n$-sigraph $\mathcal{RL}_r(S_n) = (\mathcal{RL}_r(G), \sigma')$, where $\mathcal{RL}_r(G)$ is the underlying graph of $\mathcal{RL}_r(S_n)$, where for any edge $PQ$ in $\mathcal{RL}_r(S_n)$, $\sigma'(PQ) = \sigma(P)\sigma(Q)$.

Hence, we shall call a given $n$-sigraph $S_n$ is a *restricted super line $n$-sigraph of index $r$* if it is isomorphic to the restricted super line $n$-sigraph of index $r$, $\mathcal{RL}_r(S'_n)$ of some $n$-sigraph $S'_n$. In the following subsection, we shall present a characterization of restricted super line $n$-sigraph of index $r$.

The following result indicates the limitations of the notion $\mathcal{RL}_r(S_n)$ as introduced above, since the entire class of $i$-unbalanced $n$-sigraphs is forbidden to be restricted super line $n$-sigraphs of index $r$.

**Proposition 2.1.** *For any $n$-sigraph $S_n = (G, \sigma)$, its $\mathcal{RL}_r(S_n)$ is $i$-balanced.*

*Proof.* Let $\sigma'$ denote the $n$-tuple of $\mathcal{RL}_r(S_n)$ and let the $n$-tuple $\sigma$ of $S_n$ be treated as an $n$-marking of the vertices of $\mathcal{RL}_r(S_n)$. Then by definition of $\mathcal{RL}_r(S_n)$ we see that $\sigma'(P, Q) = \sigma(P)\sigma(Q)$, for every edge $PQ$ of $\mathcal{RL}_r(S_n)$ and hence, by Proposition 1.1, the result follows. □

For any positive integer $k$, the $k^{th}$ iterated restricted super line $n$-sigraph of index $r$, $\mathcal{RL}_r(S_n)$ of $S_n$ is defined as follows:

$$\mathcal{RL}_r^0(S_n) = S_n,\ \mathcal{RL}_r^k(S_n) = \mathcal{RL}_r(\mathcal{RL}_r^{k-1}(S_n))$$

**Corollary 2.2.** *For any $n$-sigraph $S_n = (G, \sigma)$ and any positive integer $k$, $\mathcal{RL}_r^k(S_n)$ is $i$-balanced.*

In [16], the authors introduced the notion of the *super line $n$-sigraph*, which generalizes the notion of line $n$-sigraph [18]. The *super line $n$-sigraph of index $r$* of an $n$-sigraph $S_n = (G, \sigma)$ as an $n$-sigraph $\mathcal{L}_r(S_n) = (\mathcal{L}_r(G), \sigma')$, where $\mathcal{L}_r(G)$ is the underlying graph of $\mathcal{L}_r(S_n)$, where for any edge $PQ$ in $\mathcal{L}_r(S_n)$, $\sigma'(PQ) = \sigma(P)\sigma(Q)$. The above notion restricted super line $n$-sigraph is another generalization of line $n$-sigraphs.

**Proposition 2.3.** (**P.S.K.Reddy et al.** [16])
*For any $n$-sigraph $S_n = (G, \sigma)$, its $\mathcal{L}_r(S_n)$ is $i$-balanced.*

In [4], the author characterized whose restricted super line graphs of index $r$ that are isomorphic to $\mathcal{L}_r(G)$.

**Proposition 2.4.**(**K. Manjula** [4])
*For a graph $G = (V, E)$, $\mathcal{RL}_r(G) \cong \mathcal{L}_r(G)$ if, and only if, $G$ is either $K_{1,2} \cup nK_2$ or $nK_2$.*

We now characterize $n$-sigraphs those $\mathcal{RL}_r(S_n)$ are switching equivalent to their $\mathcal{L}_r(S_n)$.

**Proposition 2.5.** *For any $n$-sigraph $S_n = (G, \sigma)$, $\mathcal{RL}_r(S_n) \sim \mathcal{L}_r(S_n)$ if, and only if, $G$ is either $K_{1,2} \cup nK_2$ or $nK_2$.*

*Proof.* Suppose $\mathcal{RL}_r(S_n) \sim \mathcal{L}_r(S_n)$. This implies, $\mathcal{RL}_r(G) \cong \mathcal{L}_r(G)$ and hence by Proposition 2.4, we see that the graph $G$ must be isomorphic to either $K_{1,2} \cup nK_2$ or $nK_2$.

Conversely, suppose that $G$ is either $K_{1,2} \cup nK_2$ or $nK_2$. Then $\mathcal{RL}_r(G) \cong \mathcal{L}_r(G)$ by Proposition 2.4. Now, if $S_n$ any $n$-sigraph on any of these graphs, by Proposition 2.1 and Proposition 2.3, $\mathcal{RL}_r(S_n)$ and $\mathcal{L}_r(S_n)$ are $i$-balanced and hence, the result follows from Proposition 1.2. □

We now characterize $n$-sigraphs those $\mathcal{RL}_r(S_n)$ are isomorphic to their $\mathcal{L}_r(S_n)$. The following result is a stronger form of the above result.

**Proposition 2.6.** *For any $n$-sigraph $S_n = (G, \sigma)$, $\mathcal{RL}_r(S_n) \cong \mathcal{L}_r(S_n)$ if, and only if, $G$ is either $K_{1,2} \cup nK_2$ or $nK_2$.*

*Proof.* Clearly $\mathcal{RL}_r(S_n) \cong \mathcal{L}_r(S_n)$, where $G$ is either $K_{1,2} \cup nK_2$ or $nK_2$. Consider the map $f : V(\mathcal{RL}_r(G)) \to V(\mathcal{L}_r(S))$ defined by $f(e_1e_2, e_2e_3) = (e'_1e'_2, e'_2e'_3)$ is an isomorphism. Let $\sigma$ be any $n$-tuple on $K_{1,2} \cup nK_2$ or $nK_2$. Let $e = (e_1e_2, e_2e_3)$ be an edge in $\mathcal{RL}_r(G)$, where $G$ is $K_{1,2} \cup nK_2$ or $nK_2$. Then the $n$-tuple of the edge $e$ in $\mathcal{RL}_r(G)$ is the $\sigma(e_1e_2)\sigma(e_2e_3)$ which is the $n$-tuple of the edge $(e'_1e'_2, e'_2e'_3)$ in $\mathcal{L}_r(G)$, where $G$ is $K_{1,2} \cup nK_2$ or $nK_2$. Hence the map $f$ is also an $n$-sigraph isomorphism between $\mathcal{RL}_r(S_n)$ and $\mathcal{L}_r(S_n)$. □

## 3. Characterization of Restricted Super Line $n$-sigraphs $\mathcal{RL}_r(S_n)$

The following result characterize $n$-sigraphs which are restricted super line $n$-sigraphs of index $r$.

**Proposition 3.1.** *An $n$-sigraph $S_n = (G, \sigma)$ is a restricted super line $n$-sigraph of index $r$ if and only if $S_n$ is $i$-balanced $n$-sigraph and its underlying graph $G$ is a restricted super line graph of index $r$.*

*Proof.* Suppose that $S_n$ is $i$-balanced and $G$ is a $\mathcal{RL}_r(G)$. Then there exists a graph $H$ such that $\mathcal{L}_r(H) \cong G$. Since $S_n$ is $i$-balanced, by Proposition 1.1, there exists an $n$-marking $\mu$ of $G$ such that each edge $uv$ in $S_n$ satisfies $\sigma(uv) = \mu(u)\mu(v)$. Now consider the $n$-sigraph $S'_n = (H, \sigma')$, where for any edge $e$ in $H$, $\sigma'(e)$ is the

$n$-marking of the corresponding vertex in $G$. Then clearly, $\mathcal{RL}_r(S'_n) \cong S_n$. Hence $S_n$ is a restricted super line $n$-sigraph of index $r$.

Conversely, suppose that $S_n = (G, \sigma)$ is a restricted super line $n$-sigraph of index $r$. Then there exists an $n$-sigraph $S'_n = (H, \sigma')$ such that $\mathcal{RL}_r(S'_n) \cong S_n$. Hence $G$ is the $\mathcal{RL}_r(G)$ of $H$ and by Proposition 2.1, $S_n$ is $i$-balanced. □

If we take $r = 1$ in $\mathcal{RL}_r(S_n)$, then this is the ordinary line $n$-sigraph. In [18], the authors obtained structural characterization of line $n$-sigraphs and clearly Proposition 3.1 is the generalization of line signed graphs.

**Proposition 3.2.** *An $n$-sigraph $S_n = (G, \sigma)$ is a line $n$-sigraph if, and only if, $S_n$ is $i$-balanced $n$-sigraph and its underlying graph $G$ is a line graph.*

## 4. Complementation

In this section, we investigate the notion of complementation of a graph whose edges have signs (a *sigraph*) in the more general context of graphs with multiple signs on their edges. We look at two kinds of complementation: complementing some or all of the signs, and reversing the order of the signs on each edge.

For any $m \in H_n$, the *$m$-complement* of $a = (a_1, a_2, ..., a_n)$ is: $a^m = am$. For any $M \subseteq H_n$, and $m \in H_n$, the *$m$-complement* of $M$ is $M^m = \{a^m : a \in M\}$.

For any $m \in H_n$, the *$m$-complement* of an $n$-sigraph $S_n = (G, \sigma)$, written $(S_n^m)$, is the same graph but with each edge label $a = (a_1, a_2, ..., a_n)$ replaced by $a^m$.

For an $n$-sigraph $S_n = (G, \sigma)$, the $\mathcal{RL}_r(S_n)$ is $i$-balanced (Proposition 2.1). We now examine, the condition under which $m$-complement of $\mathcal{RL}_r(S_n)$ is $i$-balanced, where for any $m \in H_n$.

**Proposition 4.1.** *Let $S_n = (G, \sigma)$ be an $n$-sigraph. Then, for any $m \in H_n$, if $\mathcal{RL}_r(G)$ is bipartite then $(\mathcal{RL}_r(S_n))^m$ is $i$-balanced.*

*Proof.* Since, by Proposition 2,1, $\mathcal{RL}_r(S_n)$ is $i$-balanced, for each $k$, $1 \leq k \leq n$, the number of $n$-tuples on any cycle $C$ in $\mathcal{RL}_r(S_n)$ whose $k^{th}$ co-ordinate are $-$ is even. Also, since $\mathcal{RL}_r(G)$ is bipartite, all cycles have even length; thus, for each $k$, $1 \leq k \leq n$, the number of $n$-tuples on any cycle $C$ in $\mathcal{RL}_r(S_n)$ whose $k^{th}$ co-ordinate are $+$ is also even. This implies that the same thing is true in any $m$-complement, where for any $m, \in H_n$. Hence $(\mathcal{RL}_r(S_n))^t$ is $i$-balanced. □

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