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ON EDGE IRREGULAR m-BIPOLAR FUZZY GRAPHS

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Nomenclature	
m-bipolar fuzzy graph	m-BPFG
Strongly edge irregular	SEIR
Strongly edge totally irregular	SETIR
Neighbourly edge irregular	NEIR
Neighbourly edge totally irregular	NETIR
Highly irregular	HIR

Abstract

In combinatory and theoretical computer science, irregular graphs are crucial. Strongly irregular graphs belong to a significant class of highly organised graphs. We define SETIR m-BPFG and SEIR m-BPFG in this study. We establish equivalence between SEIR m-BPFG and SETIR m-BPFG and investigate a few features of the former and the latter.

Keywords: m-BPFG, SEIR m-BPFG, SETIR m-BPFG, irregular m-BPFG

1. Introduction

Each of the nodes and edges of an m-polar fuzzy graph includes components, but those features are fixed. However, these elements could be bipolar. An m-BPFG has been presented based on this concept.

Bose [7] was the first to define a strongly regular graph. Regular and irregular fuzzy graphs were first proposed by Nagoorgani et al. [8, 9]. Radha and Kumaravel [10] were the ones who initially proposed the idea of a substantially regular fuzzy graph. The paper introduces the notion of strongly edge irregular and strongly edge entirely irregular m-BPFGs. Bose [7] was the first to define a strongly regular graph. Regular and irregular fuzzy graphs were first proposed by Nagoorgani et al. [8, 9]. The idea of SEIR and SETIR m-BPFGs is introduced in this study. Additionally, certain aspects of them are investigated to define it and explored some of their characteristics.

2. Preliminaries

Prior to creating the m-BPFG, we presumptively consider:

Define an equivalency relation $\leftrightarrow, N\times N-\{(r,r): r\in N\}$ on the basis of the following $(\gamma_1,\delta_1)\leftrightarrow(\gamma_2,\delta_2)\Leftrightarrow$ either $(\gamma_1,\delta_1)=(\gamma_2,\delta_2)$ or $\gamma_1=\delta_2, \delta_1=\gamma_2$ for a given set N.

In this case, the Quotient Set is indicated by $\overleftrightarrow{N^2}$.

Definition 2.1: [5] A 3-tuple $Z=(N,A,B)$ is an m-BPFG of a graph $Z^*=(N,E)$, where $A=\left\langle\left[p_j\circ\Psi_A^p, p_j\circ\Psi_A^n\right]_{j=1}^m\right\rangle, p_j\circ\Psi_A^p: N\to[0,1]$ and $p_j\circ\Psi_A^n: V\to[-1,0]$ is an m-BPFS on N and $B=\left\langle\left[p_j\circ\Psi_B^p, p_j\circ\Psi_B^n\right]_{j=1}^m\right\rangle, p_j\circ\Psi_B^p:\overleftrightarrow{N^2}\to[0,1]$ and $p_j\circ\Psi_B^n:\overleftrightarrow{N^2}\to[-1,0]$ is an m-BPFS in $\overleftrightarrow{N^2}$ such that $p_j\circ\Psi_B^p(\tau,\varsigma)\le\min\{p_j\circ\Psi_A^p(\tau), p_j\circ\Psi_A^p(\varsigma)\}$, $p_j\circ\Psi_B^n(\tau,\varsigma)\ge\max\{p_j\circ\Psi_A^n(\tau), p_j\circ\Psi_A^n(\varsigma)\}$ for all $(\tau,\varsigma)\in\overleftrightarrow{N^2}$, $j=1,2,\cdots,m$ and $p_j\circ\Psi_B^p(\tau,\varsigma)=p_j\circ\Psi_B^n(\tau,\varsigma)=0$ for all $(\tau,\varsigma)\in\overleftrightarrow{N^2}-E$.

Definition 2.2: An m-BPFG node's $\gamma\in N$ neighbourhood degree in $Z=(N,A,B)$ is described as $d_{Nb}(\gamma)=\left\langle\left[p_j\circ d_{Nb}^p(\gamma), p_j\circ d_{Nb}^n(\gamma)\right]_{j=1}^m\right\rangle=\left\langle\left[\sum_{t\in Nb(\gamma)}p_j\circ\Psi_A^p(t), \sum_{t\in Nb(\gamma)}p_j\circ\Psi_A^n(t)\right]\right\rangle$.

Definition 2.3: The open neighbourhood degree of a node $\gamma\in N$ in an m-BPFG $Z=(N,A,B)$ is defined as

$$d_Z(\gamma)=\left\langle\left[p_j\circ d_Z^p(\gamma), p_j\circ d_Z^n(\gamma)\right]_{j=1}^m\right\rangle=\left\langle\left[\sum_{\substack{\gamma\ne\delta\\(\gamma,\delta)\in E}}p_j\circ\Psi_B^p(\gamma,\delta), \sum_{\substack{\gamma\ne\delta\\(\gamma,\delta)\in E}}p_j\circ\Psi_B^n(\gamma,\delta)\right]_{j=1}^m\right\rangle$$

Definition 2.4: The closed neighbourhood degree of a node $\gamma\in N$ in an m-BPFG $Z=(N,A,B)$ is defined as

$$d_Z[\gamma]=\left\langle\left[p_j\circ d_G^p[\gamma], p_j\circ d_G^n[\gamma]\right]_{j=1}^m\right\rangle=\left\langle\left[\sum_{\substack{\gamma\ne\delta\\(\gamma,\delta)\in E}}p_j\circ\Psi_B^p(\gamma,\delta), \sum_{\substack{\gamma\ne\delta\\(\gamma,\delta)\in E}}p_j\circ\Psi_B^n(\gamma,\delta)\right]_{j=1}^m\right\rangle+\left\langle\left[p_j\circ\Psi_A^p(\gamma), p_j\circ\Psi_A^n(\gamma)\right]_{j=1}^m\right\rangle$$

Definition 2.5: If all of the nodes have the same open neighbourhood degree $\langle[\eta_j^p,\eta_j^n]_{j=1}^m\rangle$, then an m-BPFG Z of Z^* is said to be $\langle[\eta_j^p,\eta_j^n]_{j=1}^m\rangle$-regular.

Definition 2.6: If all of the nodes have the same closed neighbourhood degree $\langle[\gamma_j^p,\gamma_j^n]_{j=1}^m\rangle$, then an m-BPFG Z of Z^* is said to be $\langle[\gamma_j^p,\gamma_j^n]_{j=1}^m\rangle$-totally regular.

Definition 2.7: An m-BPFG Z of Z^* is said to be irregular if there exists a node which is adjacent to node with different degree.

3. Irregular graphs

In this section some irregular graphs are discussed.

Definition 3.1: Let Z of Z^* be an m- BPFG. Then Z is said to be HIR m-BPFG if each node of Z is adjacent to nodes with different degrees.

Definition 3.2: Let Z be an m-BPFG. Then Z is said to be NEIR m-BPFG if each pair of adjacent edges have different degrees.

Definition 3.3: Let Z be an m- BPFG. Then Z is said to be NETIR m-BPFG if each pair of adjacent edges have different total degrees.

Definition 3.4: Let Z be an m-BPFG. Then

(i) If each pair of edges has a different degree, then Z is called **SEIR** m-BPFG. (i.e. no two edges have the equal degree) [5].

(ii) If each pair of edges has a different total degree, then Z called **SETIR** m-BPFG. (i.e. no two edges have the equal degree) [5].

Theorem 3.1: Let $Z = (N, A, B)$ be an m-BPFG of Z^* where B is constant. Then Z is SEIR m-BPFG if and only if Z is SETIR m-BPFG.

Proof: Let $B(\gamma,\delta)=\left\langle\left[p_j\circ\psi_B^p(\gamma,\delta),p_j\circ\psi_B^n(\gamma,\delta)\right]_{j=1}^m\right\rangle=\left\langle\left[k_j^p,k_j^n\right]_{j=1}^m\right\rangle$ for all $(\gamma,\delta)\in E$,where $k_j^p\in[0,1]$ and $k_j^n\in[-1,0]$.

Let Z be SEIR m-BPFG.

$\Leftrightarrow d_Z(\gamma_1,\gamma_2)\neq d_Z(\delta_1,\delta_2)$ for all $(\gamma_1,\gamma_2),(\delta_1,\delta_2)\in E$

$\Leftrightarrow d_Z(\gamma_1,\gamma_2)+\left\langle\left[k_j^p,k_j^n\right]_{j=1}^m\right\rangle\neq d_Z(\delta_1,\delta_2)+\left\langle\left[k_j^p,k_j^n\right]_{j=1}^m\right\rangle$ for all $(\gamma_1,\gamma_2),(\delta_1,\delta_2)\in E$

$\Leftrightarrow d_Z(\gamma_1,\gamma_2)+B(\gamma_1,\gamma_2)\neq d_Z(\delta_1,\delta_2)+B(\delta_1,\delta_2)$ for all $(\gamma_1,\gamma_2),(\delta_1,\delta_2)\in E$

$\Leftrightarrow td_Z(\gamma_1,\gamma_2)\neq td_Z(\delta_1,\delta_2)$ for all $(\gamma_1,\gamma_2),(\delta_1,\delta_2)\in E$

$\Leftrightarrow Z$ is SETIR m-BPFG.

Remark 3.1: B might not be a be a constant function if $Z = (N, A, B)$ is both SEIR and SETIR m-BPFG.

Theorem 3.2: If Z is SEIR m-BPFG, then Z is NEIR m-BPFG.

Proof: As Z is SEIR m-BPFG, therefore each pair of edges in Z have different degrees. Hence each pair of adjacent edges have different degrees.

So, Z is NEIR m-BPFG.

Theorem 3.3: If Z is SETIR-BPFG, then Z is NETIR m-BPFG.

Proof: Let Z be an m-BPFG and SETIR.

Each pair of edges in Z has a different total degree, hence each pair of adjacent edges also has a different total degree, making Z a NETIR m-BPFG.

Theorem 3.4: Let $Z = (N, A, B)$ be an m-BPFG of Z^* where B is constant. If Z is SEIR m-BPFG, then Z is an irregular m-BPFG.

Proof: Let $B(\gamma,\delta)=\left\langle\left[p_j\circ\psi_B^p(\gamma,\delta),\ p_j\circ\psi_B^n(\gamma,\delta)\right]_{j=1}^m\right\rangle=\left\langle\left[k_j^p,\ k_j^n\right]_{j=1}^m\right\rangle$ for all $(\gamma,\delta)\in E$

,where $k_j^p \in [0, 1]$ and $k_j^n \in [-1, 0]$. As Z is SEIR, we have each pair of edges will have different degrees. Assume that the two adjacent edges (γ_1, δ_1) and (δ_1, η_1) having distinct degrees.

This provides that $d_Z(\gamma_1, \delta_1) \neq d_Z(\delta_1, \eta_1)$

$$\Rightarrow d_Z(\gamma_1) + d_Z(\delta_1) - 2\left\langle \left[p_j \circ \psi_B^p(\gamma_1, \delta_1),\ p_j \circ \psi_B^n(\gamma_1, \delta_1) \right]_{j=1}^m \right\rangle \neq$$

$$d_Z(\delta_1) + d_Z(\eta_1) - 2\left\langle \left[p_j \circ \psi_B^p(\delta_1, \eta_1),\ p_j \circ \psi_B^n(\delta_1, \eta_1) \right]_{j=1}^m \right\rangle$$

$$d_Z(\gamma_1) + d_Z(\delta_1) - 2\left\langle \left[k_j^p,\ k_j^n \right]_{j=1}^m \right\rangle \neq d_Z(\delta_1) + d_Z(\eta_1) - 2\left\langle \left[k_j^p,\ k_j^n \right]_{j=1}^m \right\rangle$$

$$\Rightarrow d_Z(\gamma_1) \neq d_Z(\eta_1).$$

This indicates that the node δ_1 that is adjacent to the nodes γ_1 and η_1 have different degrees. As a result, Z is irregular.

Theorem 3.5: Let $Z = (N, A, B)$ be an m-BPFG of Z^* where B is constant. If Z is SEIR m-BPFG then Z is HIR m-BPFG.

Proof: Let $B(\alpha, \beta) = \left\langle \left[p_j \circ \psi_B^p(\alpha, \beta),\ p_j \circ \psi_B^n(\alpha, \beta) \right]_{j=1}^m \right\rangle = \left\langle \left[k_j^p,\ k_j^n \right]_{j=1}^m \right\rangle$ for all $(\alpha, \beta) \in E,$ where $k_j^p \in [0, 1]$ and $k_j^n \in [-1, 0].$ Assume that α_2 be any node adjacent with the nodes α_1, α_3 and α_4. Thus $(\alpha_1, \alpha_2), (\alpha_2, \alpha_3), (\alpha_2, \alpha_4)$ are adjacent edges in Z. Let us consider that Z is SEIR m-BPFG. Thus each pair of edges in Z have different degrees. Hence, each pair of adjacent edges in Z have different degrees.

Hence, $d_Z(\alpha_1, \alpha_2) \neq d_Z(\alpha_2, \alpha_3) \neq d_Z(\alpha_2, \alpha_4)$

$$\Rightarrow d_Z(\alpha_1) + d_Z(\alpha_2) - 2\left\langle \left[p_j \circ \psi_B^p(\alpha_1, \alpha_2),\ p_j \circ \psi_B^n(\alpha_1, \alpha_2) \right]_{j=1}^m \right\rangle \neq$$

$$d_Z(\alpha_2) + d_Z(\alpha_3) - 2\left\langle \left[p_j \circ \psi_B^p(\alpha_2, \alpha_3),\ p_j \circ \psi_B^n(\alpha_2, \alpha_3) \right]_{j=1}^m \right\rangle \neq$$

$$d_Z(\alpha_2) + d_Z(\alpha_4) - 2\left\langle \left[p_j \circ \psi_B^p(\alpha_2, \alpha_4),\ p_j \circ \psi_B^n(\alpha_2, \alpha_4) \right]_{j=1}^m \right\rangle$$

$$\Rightarrow d_Z(\alpha_1) + d_Z(\alpha_2) - 2\left\langle \left[k_j^p,\ k_j^n \right]_{j=1}^m \right\rangle \neq d_Z(\alpha_2) + d_Z(\alpha_3) - 2\left\langle \left[k_j^p,\ k_j^n \right]_{j=1}^m \right\rangle \neq$$

$$d_Z(\alpha_2) + d_Z(\alpha_4) - 2\left\langle \left[k_j^p,\ k_j^n \right]_{j=1}^m \right\rangle$$

$$\Rightarrow d_Z(\alpha_1) \neq d_Z(\alpha_3) \neq d_Z(\alpha_4).$$

Hence the node α_2 is adjacent to the nodes α_1, α_3 and α_4 with different degrees.

As a result, Z is HIR.

4. Some Properties of Neighbourly Edge Totally Irregular m-BPFGs

In this part, we look at a few SETIR m-BPFG and NETIR m-BPFG features.

Definition 4.1: A walk in a directed graph $\overrightarrow{Z} = (\overrightarrow{N}, E)$ is a series of steps $w = v_1\overrightarrow{e_1}v_2\overrightarrow{e_2}\cdots v_{k-1}\overrightarrow{e_{k-1}}\,v_k$ of nodes v_i and arcs $\overrightarrow{e_i}$ of $\overrightarrow{Z}$ such that the head and tail of $\overrightarrow{e_i}$ are v_i and v_{i+1} for all $i = 1, 2, \cdots, k-1$ respectively. If $v_1 = v_k$, then a walk is said to be closed. A walk with different arcs is called a trail. A walk with different nodes is called a path. If $v_1 = v_k$, then the path $v_1, v_2, \cdots v_k$ with $k \geq 3$ is a cycle. The number of edges on a path or cycle determines its length.

Definition 4.2: If every edge of an m-BPFG $Z = (N, A, B)$ of Z^* is having the equal total degree $\langle[\delta_j^p, \delta_j^n]_{j=1}^m\rangle$, thus Z is said to be totally edge regular m-BPFG.

Property 4.1: Let $Z = (N, A, B)$ be an m-BPFG of Z^* and B is constant. If Z is SETIR m-BPFG, thus Z is HIR m-BPFG.

Property 4.2: Let $Z = (N, A, B)$ be an m-BPFG of Z^* that is a path of $2r$ $(r > 1)$ nodes. If the membership value of the edges $f_1, f_2, \cdots, f_{2r-1}$ are $\left(\left[b_j^{p(1)}, b_j^{n(1)}\right]_{j=1}^m\right), \left(\left[b_j^{p(2)}, b_j^{n(2)}\right]_{j=1}^m\right), \cdots, \left(\left[b_j^{p(2r-1)}, b_j^{n(2r-1)}\right]_{j=1}^m\right)$ respectively such that $b_j^{p(1)} < b_j^{p(2)} < \cdots < b_j^{p(2r-1)}$ and $b_j^{n(1)} > b_j^{n(2)} > \cdots > b_j^{n(2r-1)}$, then Z is both SEIR and SETIR. (Here, $f_i = v_i v_{i+1}$ for $i = 1, 2, \cdots, (2r-1)$).

Theorem 4.1: Let $Z = (N, A, B)$ be an m-BPFG of Z^* that is a path of cycle r $(r \geq 4)$nodes. If the membership value of the edges $f_1, f_2, \cdots, f_r$ are $\left(\left[b_j^{p(1)}, b_j^{n(1)}\right]_{j=1}^m\right), \left(\left[b_j^{p(2)}, b_j^{n(2)}\right]_{j=1}^m\right), \cdots, \left(\left[b_j^{p(r)}, b_j^{n(r)}\right]_{j=1}^m\right)$ respectively such that $b_j^{p(1)} < b_j^{p(2)} < \cdots < b_j^{p(r)}$, $b_j^{n(1)} > b_j^{n(2)} > \cdots > b_j^{n(r)}$, then Z is both SEIR and SETIR.

Proof: Let $f_1, f_2, \cdots, f_r$ be the edges of the cycle Z^* in that order.

Thus, we get

$$d_Z(v_i) = \left(\left[b_j^{p(i-1)} + b_j^{p(i)}, b_j^{n(i-1)} + b_j^{n(i)}\right]_{j=1}^m\right) \text{ for } i = 2, 3, \cdots, r \text{ and}$$

$$d_Z(v_1) = \left(\left[b_j^{p(1)} + b_j^{p(r)}, b_j^{n(1)} + b_j^{n(r)}\right]_{j=1}^m\right),$$

$$d_Z(f_i) = \left(\left[b_j^{p(i-1)} + b_j^{p(i+1)}, b_j^{n(i-1)} + b_j^{n(i-1)}\right]_{j=1}^m\right) \text{ for } i = 2, 3, \cdots, (r-1),$$

$$d_Z(f_1) = \left(\left[b_j^{p(2)} + b_j^{p(r)}, b_j^{n(2)} + b_j^{n(r)}\right]_{j=1}^m\right),$$

$$d_Z(f_r) = \left(\left[b_j^{p(1)} + b_j^{p(r-1)}, b_j^{n(1)} + b_j^{n(r-1)}\right]_{j=1}^m\right)$$

So, Z is SEIR m-BPFG.

Again, since

$$td_Z(f_i) = \left(\left[b_j^{p(i-1)} + b_j^{p(i+1)} + b_j^{p(i)}, b_j^{n(i-1)} + b_j^{n(i-1)} + b_j^{n(i)}\right]_{j=1}^m\right) \text{ for } i = 2, 3, \cdots, (r-1),$$

$$td_Z(f_1)=\left(\left[b_j^{p(2)}+b_j^{p(1)}+b_j^{p(r)},\ b_j^{n(2)}+b_j^{n(1)}+b_j^{n(r)}\right]_{j=1}^m\right),$$

$$td_Z(f_r)=\left(\left[b_j^{p(1)}+b_j^{p(r)}+b_j^{p(r-1)},\ b_j^{n(1)}+b_j^{n(r)}+b_j^{n(r-1)}\right]_{j=1}^m\right),$$

as a result, Z is SETIR m-BPFG.

Theorem 4.2: Let $Z=(N,A,B)$ be an m-BPFG of Z^* that is a star $K_{1,r}$ If There are no two edges with the same membership values, thus Z is both SEIR and totally edge regular m-BPFG.

Proof: Let the nodes adjacent to the node l_0 be $l_1,l_2,\cdots,l_r$ .Let the edges of the star Z^* be $f_1,f_2,\cdots,f_r$, with the membership values

$\left(\left[b_j^{p(1)},\ b_j^{n(1)}\right]_{j=1}^m\right),\left(\left[b_j^{p(2)},\ b_j^{n(2)}\right]_{j=1}^m\right),\cdots,\left(\left[b_j^{p(r)},\ b_j^{n(r)}\right]_{j=1}^m\right)$ such that

$\left(\left[b_j^{p(1)},\ b_j^{n(1)}\right]_{j=1}^m\right)\neq\left(\left[b_j^{p(2)},\ b_j^{n(2)}\right]_{j=1}^m\right)\neq\cdots\neq\left(\left[b_j^{p(r)},\ b_j^{n(r)}\right]_{j=1}^m\right)$. Then

$$d_Z\left(f_i=(l_0,\ l_i)\right)=d_Z(l_0)+d_Z(l_i)-2B(l_0,\ l_i)$$

$$=\left(\left[b_j^{p(1)}+b_j^{p(2)}+\cdots+b_j^{p(r)},\ b_j^{n(1)}+b_j^{n(2)}+\cdots+b_j^{n(r)}\right]_{j=1}^m+\left[b_j^{p(i)},\ b_j^{n(i)}\right]-2\left[b_j^{p(i)},\ b_j^{n(i)}\right]\right)$$

$$=\left(\left[b_j^{p(1)}+b_j^{p(2)}+\cdots+b_j^{p(r)},\ b_j^{n(1)}+b_j^{n(2)}+\cdots+b_j^{n(r)}\right]_{j=1}^m-\left[b_j^{p(i)},\ b_j^{n(i)}\right]\right)\text{ for } i=1,\ 2,\ \cdots,\ r.$$

All of the edges' degrees can be seen to vary. Z is hence SEIR.

Also $td_Z\left(f_i=(l_0,\ l_i)\right)$

$$=\left(\left[b_j^{p(1)}+b_j^{p(2)}+\cdots+b_j^{p(r)},\ b_j^{n(1)}+b_j^{n(2)}+\cdots+b_j^{n(r)}\right]_{j=1}^m-\left[b_j^{p(i)},\ b_j^{n(i)}\right]+\left[b_j^{p(i)},\ b_j^{n(i)}\right]\right)$$

$$=\left(\left[b_j^{p(1)}+b_j^{p(2)}+\cdots+b_j^{p(r)},\ b_j^{n(1)}+b_j^{n(2)}+\cdots+b_j^{n(r)}\right]_{j=1}^m\right)\text{ for } i=1,\ 2,\ \cdots,\ r.$$

As a result, Z is totally edge regular because all of the edges have the same total number of degree.

Conclusions

We introduce and investigate the idea of SEIR and SETIR m-BPFGs. SETIR and SEIR m-BPFGs are described. Researchers have looked into a number of their crucial characteristics.

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