Note

MINIMUM EDGE CUTS IN DIAMETER 2 GRAPHS

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Abstract

Plesnik proved that the edge connectivity and minimum degree are equal for diameter 2 graphs. We provide a streamlined proof of this fact and characterize the diameter 2 graphs with a nontrivial minimum edge cut.

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Let $G$ be a graph. For $S, T \subseteq V (G)$, let $[S, T]$ be the set of edges with one end in $S$ and the other in $T$. An edge cut of a graph $G$ is a set $X = [S, T]$, of edges so that $G - X$ has more components than $G$. The edge connectivity $\lambda (G)$ of a connected graph is the smallest size of an edge cut. A disconnected graph has $\lambda (G) = 0$. Often we can express an edge cut as $[S, \overline{S}]$, where $\overline{S} = V (G) \setminus S$.

Denote the minimum degree of $G$ by $\delta (G)$. It is well-known that $\lambda (G) \leq \delta (G)$, since the edges incident with a vertex of minimum degree form an edge cut. Plesnik proved that this is an equality for diameter 2 graphs. We present a shorter proof.
Theorem 1 [3]. If $G$ has diameter 2, then $\lambda(G) = \delta(G)$.

Proof. Let $[S, \overline{S}]$ be a minimum edge cut. Now $S$ and $\overline{S}$ cannot both have vertices $u$ and $v$ that are not incident with $[S, \overline{S}]$, for then $\text{diam}(G) \geq d(u, v) \geq 3$. Say $S$ has every vertex incident with $[S, \overline{S}]$. Thus $|S| \leq |[S, \overline{S}]| = \lambda(G) \leq \delta(G)$. Each vertex in $S$ is incident with at most $|S| - 1$ edges in $G[S]$, and so at least $\delta(G) - |S| + 1$ edges in $[S, \overline{S}]$. Thus

$$\lambda(G) = |[S, \overline{S}]| \geq |S| \left(\delta(G) - |S| + 1\right).$$

This last expression attains its minimum value of $\delta(G)$ when $|S| = 1$ or $|S| = \delta(G)$. In both cases we have $\lambda(G) \geq \delta(G)$, so $\lambda(G) = \delta(G)$. 

The following corollary follows from the proof of this theorem.

Corollary 2 [1]. If $G$ has diameter 2, then one of the subgraphs on one side of a minimum edge cut is either $K_1$ or $K_{\delta(G)}$.

A trivial edge cut is an edge cut whose deletion isolates a single vertex. To study those diameter 2 graphs with a nontrivial minimum edge cut, we define the following set of graphs.

Definition. Let $\mathcal{G}$ be the set of graphs that contains the Cartesian product $K_2 \square K_2$, $n \geq 4$, and those graphs that can be constructed as follows. Let $H_1$ be a graph with order $d > 1$ and $\delta(H_1) \geq d - r - 1$ and $H_2$ be a graph with order $r$. Add a perfect matching between $K_d$ and $H_1$ and join all the vertices of $H_1$ and $H_2$ (see Figure 1).

![Figure 1](image_url)

Figure 1. A graph in $\mathcal{G}$ with $d = 3$, $H_1 = P_3$, and $H_2 = 2K_1$.

Theorem 3. A graph has diameter 2 and contains a non-trivial minimum edge cut if and only if it is in set $\mathcal{G}$. 
Proof. (⇐) It is readily checked that a graph $G \in \mathbb{G}$ has diameter 2, $\delta (G) = d = \lambda (G)$, and contains a nontrivial minimum edge cut.

(⇒) Let $G$ have diameter 2 and contain a non-trivial minimum edge cut $[S, \overline{S}]$, and let $d = \delta (G)$. Then (say) $S = K_d$, and the order of $\overline{S}$ is at least $d$. If it is exactly $d$, then $G = K_d \sqcup K_2$. If not, then $\overline{S}$ contains vertices not adjacent to any vertex of $K_d$. Let $H_2$ be the subgraph induced by these vertices and $H_1 = \overline{S} - H_2$. Then each vertex of $H_2$ is adjacent to each vertex of $H_1$ since otherwise $G$ would not have diameter 2. Since $G$ has minimum degree $d$, $H_1$ must have minimum degree at least $d - r - 1$.

Corollary 4. If $G \in \mathbb{G}$, then it has between $d$ and $\max \{n - d, 3d - 1\}$ trivial minimum edge cuts.

Proof. The number of trivial minimum edge cuts is the number of vertices of minimum degree. All the vertices of $K_d$ have minimum degree, so this is at least $d$. Now $K_d \sqcup K_2$ has $n = 2d$ such vertices. If $G$ is regular, then it has at most $d + d + (d - 1)$ vertices since each vertex in $H_1$ has degree at least $1 + n (H_2)$. If $n (H_2) \geq d$ then each vertex in $H_1$ has degree more than $d$, so there are at most $n - d$ minimum degree vertices.

Corollary 5. All graphs in set $\mathbb{G}$ have a single non-trivial minimum edge cut except for $C_4$ and $C_5$.

Proof. Let $G \in \mathbb{G}$, so $\delta (G) \geq 2$. If $\delta (G) = 2$, then $C_4$ and $C_5$ have two and five nontrivial edge cuts, respectively. Now $C_5 + e$ has a single non-trivial minimum edge cut. Let $u$ and $v$ be the vertices in $H_1$. If there are at least two vertices in $H_2$, then $G$ has a spanning subgraph with $n - 4$ $u - v$ paths of length 2 and one $u - v$ path of length 3. Hence the result holds for $\delta (G) = 2$.

Let $d = \delta (G) > 2$. Assume the result holds for graphs with minimum degree $d - 1$. Then no nontrivial minimum edge cut separates vertices in $K_d$. Now $H = G - K_d$ has $\text{diam} (H) \leq 2$ and $\delta (H) \geq d - 1$. Now $H$ is not $C_4$ or $C_5$, so it has at most one nontrivial minimum edge cut. If it has such a cut, then there are at least $d - 1$ vertices on each side of it, so $n (H_2) \geq d - 2$. Then $H$ contains spanning subgraph $K_{d,n(H_2)}$. But this graph has no nontrivial minimum edge cut, so neither does $H$. Then $G$ has no other nontrivial minimum edge cut.

Finally, we consider the nature of minimum edge cuts in almost all graphs.

Theorem 6. Almost all graphs have a single minimum edge cut, which is trivial.

Proof. In random graph theory, it is known that almost all graphs have diameter 2 [1]. This implies that $\lambda (G) = \delta (G)$ for almost all graphs. Erdős and Wilson
[2] showed that almost all graphs have a unique vertex of maximum degree. By symmetry, almost all graphs have a unique vertex of minimum degree.

Those graphs with a minimum non-trivial edge cut have the structure described in Theorem 3, including at least \( \delta(G) > 1 \) vertices of minimum degree. Hence almost all graphs have a single minimum edge cut, which is trivial.

References


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