Pegasus: The second connectivity graph for large-scale quantum annealling hardware

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Pegasus is a graph which offers substantially increased connectivity between the qubits of quantum annealing hardware compared to the graph Chimera. It is the first fundamental change in the connecctivity graph of quantum annealers built by D-Wave since Chimera was introduced in 2011 for D-Wave's first commercial quntum annealer. In this article we describe an algorithm which defines the connectivity of Pegasus and we provide what we believe to be the best way to graphically visualize Pegasus in 2D and 3D in order to see which qubits couple to each other. As Supplemental Material, we provide open source codes for generating Pegasus graphs.

The 128 qubits of the first commercial quantum annealer (D-Wave One, released in 2011) were connected by a graph called Chimera, which is rather easy to describe: A 2D array of $K_{4,4}$ graphs, with one partition of each $K_{4,4}$ being also connected to the same corresopnding partition on the $K_{4,4}$ unit cell above it, and the other partition being connected to the same corresponding partition on the $K_{4,4}$ to the right of it (see Fig 1). The degree of the graph is six, since each qubit couples to four qubits within its $K_{4,4}$ unit cell, and to one qubit in a $K_{4,4}$ above it and one qubit in a $K_{4,4}$ to the right of it. All commercial quantum annealers built to date follow this graph connectivity, with just larger and larger numbers of $K_{4,4}$ unit cells (See Table 1).

Table I. Chimera graphs in all commercial quantum computers to date.

	Array of $K_{4,4}$ unit cells	Total # of qubits
D-Wave One	4×4	128
D-Wave Two	8×8	512
D-Wave 2X	12×12	1152
D-Wave 2000Q	16×16	2048

In 2018, D-Wave announced the contruction of a (not yet commercial) quantum annealer with a greater connectivity than Chimera offers, and a publicly available program (NetworkX) which allows users to generate Pegasus graphs of arbitrary size. However, no explicit description of the graph connectivity in Pegasus has been published yet, so we have had to apply the process of reverse engineering to determine it, and the following section describes our algorithm for generating Pegasus.

Figure 1.

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I. ALGORITHM FOR GENERATING PEGASUS

Start with K layers of Chimera graphs, each being an $I \times J$ array of $K_{4,4}$ unit cells (therefore we have a $I \times J \times K$ array of $K_{4,4}$ unit cells). The indices (i, j, k) will be used to decribe the location of each unit cell along the indices corresponding dimension picked from (I, J, K). Each $K_{4,4}$ cell has two partitions, labeled $l \in \{1, 2\}$, so that there's 4 qubits (vertices) for every (i, j, k, l). We will arbitrarily label these 4 qubits using two more labels: $(m, n) \in \{1, 2\}^2$. Therefore every qubit is associated with 5 indices: (i, j, k, l, m, n), with their ranges and descriptions given in Table 2.

Table II. Indices used to describe each qubit (vertex) in Pegasus

i	1 to I	Row within a Chimera layer
j	1 to J	Column within a Chimera layer
k	1 to K	Chimera layer
l	1,2	Bi-partition within $K_{4,4}$
m	1,2	Top partition within each bi-partition of $K_{4,4}$
n	1,2	Bottom partition within each bi-partition of $K_{4,4}$

We then have the connections between $K_{4,4}$ cells of a particular layer, which would normally appear in Chimera:____________.

Pegasus first adds connections within each $K_{4,4}$ cell (labeled Black). The rest of the new connections in Pegasus come from connecting $K_{4,4}$ cells between different layers of $I \times J$ Chimera graphs. The qubits of $K_{4,4}$ will be connected to three different $K_{4,4}$ cells from a specific Chimera graph (i, j) on a different Chimera layer, and each pair of connected $K_{4,4}$ cells will have eight different connecctions in the form of $K_{2,2}$:_________.

See Fig. 2.

II. ALTERNATIVE GRAPHICAL REPRESENTATIONS OF PEGASUS

III. COMPARISON TO CHIMERA AND DISCUSSION

degree 15 vs degree 6. Non-planarity, and explain how Helmut's paper claimed that D-Wave needs to make the $K_{4,4}$ cells non-planar to each other (not just non-planar within the $K_{4,4}$.