# Simulation of Quantum Cellular Automata Circuits using Neural Networks

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***Abstract***

*CMOS technology miniaturization limits have provided new alternative technologies, Quantum cellular automata (QCA) is a new technology in nanometer scale as one of the alternatives, QCA technology has large potential in terms of high space density and power dissipation with the development of faster computers and lower power consumption. This paper proposes the use of Hopfield neural network design of simple QCA cells and study device level uncertainties like stable polarization at the output cell, near to ground state configuration of QCA cells. This study is helpful to synthesize the QCA system thereby to achieve high speed and errorless circuit.*

## 1. Introduction

Quantum-dot Cellular Automata (QCA) is an emerging technology that offers a revolutionary approach to computing at nano-level [1]. The fundamental unit of QCA is QCA cell created with four quantum Dots positioned at the vertices of a square [2]. [3]. The electrons in the cell that are placed adjacent to each other will interact; as a result the polarization of one cell will be directly affected by the polarization of its neighboring cells [4]. This interaction forces between the neighboring cells able to synchronize their polarization.[5]. Therefore an array of QCA cells acts as wire and is able to transmit information from one end to another [6] [7]. The majority gate is the fundamental gate of QCA produces an output that reflects the majority of the inputs [8]. In order to create an AND gate we simply fix one of the majority gate input to 0 (P = -1). To create OR gate we fix one of inputs to 1 P = +1. The inverter or NOT gate is also simple to implement using QCA [9][10]. Clocking is the requirement for synchronization of information flow in QCA circuits. It requires a clock not only to synchronize and control information flow but clock actually provides power to run the circuit [11] [12] [13]. The cells are not powered from any other external source apart from the clock. These clocks have been proposed to control the potential barriers between the dots [14]. This paper discuss about neural network based simple QCA circuit modeling (latches, not, majority gates) to get stable polarization of the circuit. We have considered layout model of QCA circuits from [23], Since QCA technology is based on charge transfer rather than electron flow, the unpolarization of a circuit results in wrong output, so it is essential to simulate simple qca circuit with respect to its polarization. Following this, session II speaks about Hopfield neural network based QCA cell simulation for stable polarization of the output cell and to find the unstable points at the center of state space (unpolarization state).

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## 2. NEURAL NETROK BASED QCA CIRCUIT SIMULATION

QCA circuit simulation based on neural network can be used efficiently to synthesize at circuit level. In this paper we propose neural network based simulation of QCA circuits. This in turn useful for synthesis of QCA circuits by evolutionary algorithms like genetic algorithms etc [15][16][17][18]. QCA circuits can be successfully optimized in terms of its construction (no of cells), energy minimization of the output cell using neural networks. Figure 1 shows Hopfield neural network with connections between three neurons. QCA cell simulation depends on nature of input configuration and temperature, we assume standard temperature of 10k for all simulation and simple input configurations.

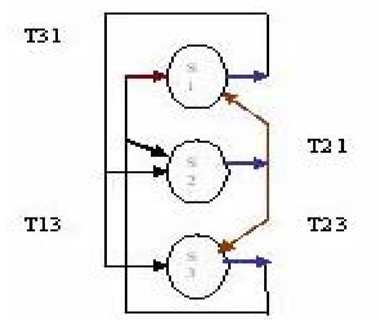



**Figure 1 Hopfield neural networks with connections between three neurons**

This network can be trained to get information about device uncertainties like ground state configuration of output cell (least polarization of the cell), steady state polarization and minimum energy required for output cell in QCA logic circuits. The network structure and synaptic weights depends on specification of problem. Output signal is generated when each neuron just adds the signal sent by other neurons and multiplied by synaptic weights. The weighted sum of input and output signal is called input and output potentials. The energy function for the network is defined as

$$E = - 1/2 \sum_{i=1}^{m} \sum_{j=1}^{m} W_{ij} P_i P_j \qquad (1)$$

Where $W_{ij}$ (i,j = 1 …m) is the synaptic weight between neurons j and i. The set of values of $W_{ij}$ forms symmetric matrix that contains synaptic weights and these weights corresponds to the energy value of a cell ranges between 2.96 milli eV to 4.34 milli eV [19] to minimize the energy of the network, the input potential is defined by

$$V_i = - \Delta E / \Delta P_i \ (I = 1…..m) \qquad (2)$$

$$V_i = \sum_{i=1}^{m} W_{ij} P_i \qquad (3)$$

Each neuron represents one cell of a QCA circuit, and have a value ranges between -1 to +1 in its polarization. Figure 2 shows QCA circuit with three cells as three neurons as in figure 1.

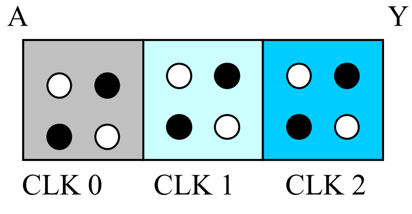
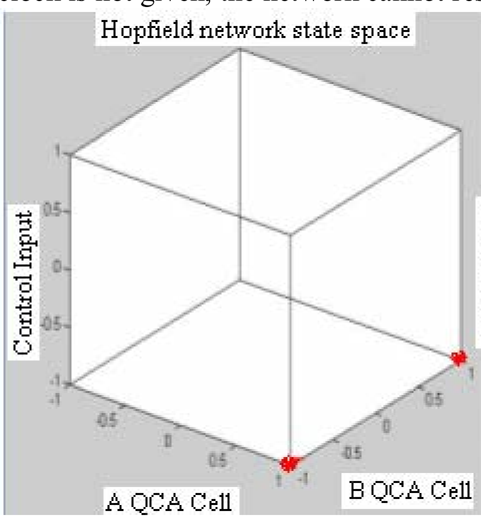


**Figure 2 Three QCA cells in serial with three clock zones 0, 1, 2**

Hopfield network that represents a neuron 1 corresponds to first cell in QCA, second neuron represents second cell and third represents third cell. We initially design Hopfield network with target stable points to get polarization of QCA cells at ground state configuration (one state of Polarization either +1 or -1). The behaviors of the Hopfield network for different initial conditions are studied. Finally network designed should give two stable points defined by target vectors as [+1, +1; -1, +1; -1,-1]. In QCA terminology when one cell polarized to +1 the other cell get effected due to tunneling between them and hence the other electron also get polarized, now the goal of the simple Hopfield network is to find the stable polarization given initial (assumed) stable points. Figure 2 shows the QCA AND logic circuit with inputs a, b and control input: y be output, given the polarization of input a and b [20],the output polarization of Y can be calculated through majority voting scheme. In Hopfield Neural network three inputs are given with clocking, figure 3 shows the stable points of QCA cell b [+1 to –1]. If the clock is not given, the network cannot respond to the input.



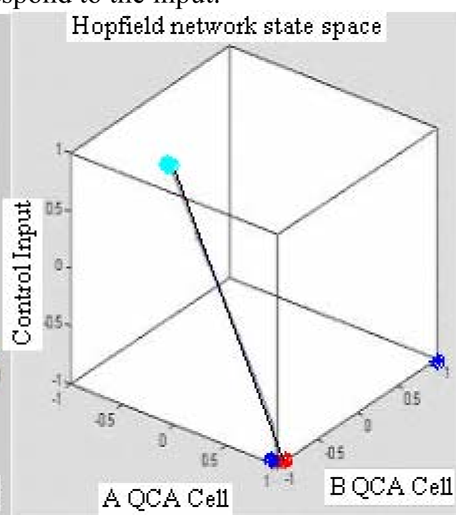




**Figure 3 QCA Cell Hopfield Figure 4 QCA Majority gate network state space.**
**(stable points are shown at the corners for input b cell [-1, + 1])**

In this network all possible states of 2N Hopfield neural network are contained within the plot boundaries. We used the function newhop that creates Hopfield network with given stable points. Newhop(T) takes one input argument, let T the matrix of R multiplied with Q (target vector) and returns a new Hopfield recurrent neural network with stable points at the vectors in T. We check that the network is stable at these points by using them as initial stable conditions. If the network is stable we would expect that the outputs Y will be the same. Hence QCA Cell output is same as per majority logic. Suppose the network gets wrong inputs: then the network can be used to correct the corrupted input vector which moves to the nearest target vector, similarly the polarization of the output cells can be made near to the ground state configuration. Simple QCA AND,OR circuit being simulated using Hopfield network, given input vector of a [+1], b[ -1] and control input [+1], code is written based on majority logic and also if control input is +1 it is logic OR operation and -1 for AND operation. We used new hop(T) function to view the stable output at y. Figure 4 shows the simulation of QCA Hopfield network for OR operation and y output cell ( neuron) reaches to a ( +1) so output y = a ( +1), blue line indicates the output cell reflects one of the inputs a to its full polarization. Suppose randomly generate a point in between +1 and –1, the network ends up at the corner as shown in figure 4.We repeat the simulation for 25 more randomly generated initial conditions between +1 to –1 of two cell QCA. These points were exactly between two target stable points. The result is that the network ends up with designed stable corner points (polarizations) as shown in figure 5.

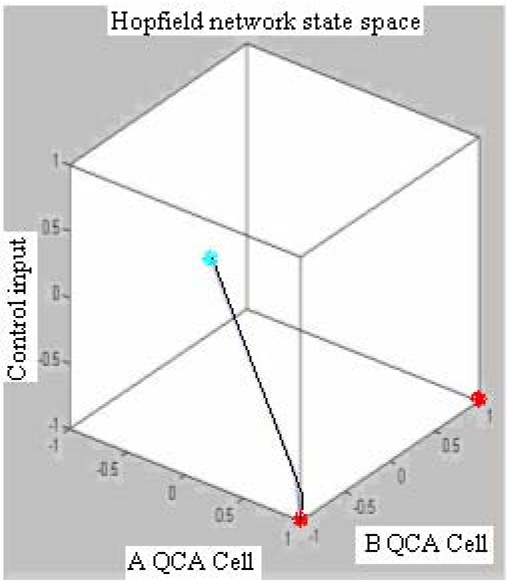



**Figure 4 Hopfield QCA network ends up with stable points at the corners.**

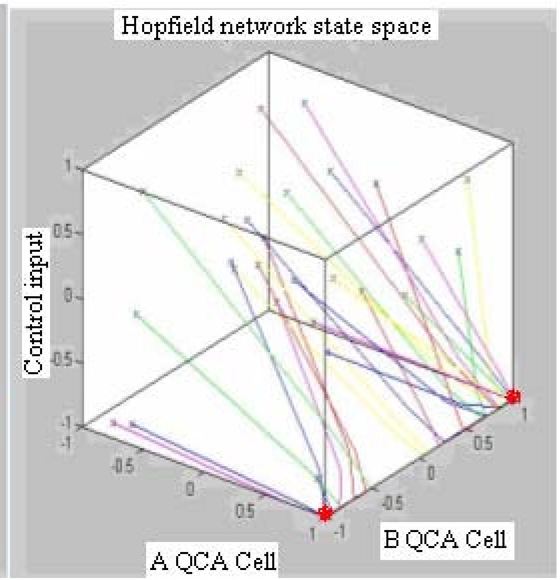



**Figure 5 Hop field QCA network with 25 randomly generated points**

The polarization of electrons in QCA cell between its targets ( + 1 to –1) being specified, then Hopfield QCA network shows undesired stable points that exists at the center of the state space or given unstable state the network ends up with stable points. These unstable points are due to higher or lower columbic interaction between cells. Clocking problems tends to unpolarize the QCA cells in turn affects neighboring cells, so there is a chance for output cell to go unpolarized. We can study from this hopfield QCA network simulation, the undesirable points exist between the cells in a circuit and as well as the polarization of the output cell. Suppose the Hopfield QCA network with exactly the stable points and some unstable points of given target say

T = [ 1.0 -1.0 -0.5 1.00 1.00 0.0; ...
0.0 0.0 0.0 0.00 0.00 0.0; ...
-1.0 1.0 0.5 -1.01 -1.00 0.0]; T vector has two cell interaction polarizations

We tested the network with above points for three QCA cells of figure 2, the result is undesirable points move into the center of the state space. It is easy to find unstable cells for given stable polarization. We validate our model with the already available bistable and coherent simulator by Walus etal [1] [2] [5] [6], our QCA Hopfield network shows the similar results in term of its polarization values.

## 3 Conclusion

We have designed QCA network based on Hopfield neural network for AND and OR majority logic gates. QCA Hopfield simulation results being compared with other simulator referenced here, our simulator shows same results with others in addition, there is a possibility of study of undesirable stable points (unpolarized cells in the network) and these points are brought to stable polarizations. Undesirable points in the network can be identified by simulating the QCA Hopfield network and it shows the unstable points are at the center space of the Hopfield state space. The simulation result shows the response can be made near to linear and useful to study the error due to clocking etc in a circuit. We conclude that evolution algorithm like neural network algorithms and genetic algorithms can be used to simulate device level uncertainties exists in nanodevices. This study may be useful for synthesizing the QCA system using evolutionary algorithms.

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