Synchronization Phenomena of Coupled Chaotic Circuits Network with Coupling Strength Depending on Number of Degree

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Abstract— **We investigate the influence of direct coupling and indirect coupling for synchronization state in the network. The node of the network is expressed by chaotic circuit. This complex network is designed that a node has two or more links except for one node with scale free property. The coupling strength is determined depending on the number of links between the nodes. In this investigation, we find that not only the direct coupling but also the indirect coupling by the path is strongly related for synchronization state.**

Keywords; Synchronization, Complex network, Chaotic Circuits

I. INTRODUCTION

In our living life, complex network can be seen in various fields such as airport network, computer network and neurons in the brain. Furthermore, synchronization phenomena observed in complex network have been investigated by many researchers [1], [2]. Especially synchronization phenomena of coupled oscillatory systems are very interesting. There are various investigations of synchronization using chaotic circuits. However, few studies focus on the difference in coupling strength [3], [4].

In this study, we focus on the path and coupling strength in coupled chaotic circuit network. We design a network that each node has different coupling strength depending the number of degree and the network has scale free property. In order to make the network which the total coupling strength of node in the network has nearly uniform, we apply the following rule to set the coupling strength. When the difference of number of degree between two nodes is large, the coupling strength between two nodes is set to small value.

By using the computer simulations, we investigate synchronization between hubs when one link is opened. Furthermore, we also investigate synchronization between hubs when another link is opened.

II. CIRCUIT MODEL

Figure 1 shows the chaotic circuit which is three dimensional autonomous circuit proposed by Shinriki *et al*. This circuit consists of one negative resister, two capacitors, one inductor and dual-directional three diodes [5]. And this circuit equation is shown in Eq. (1).

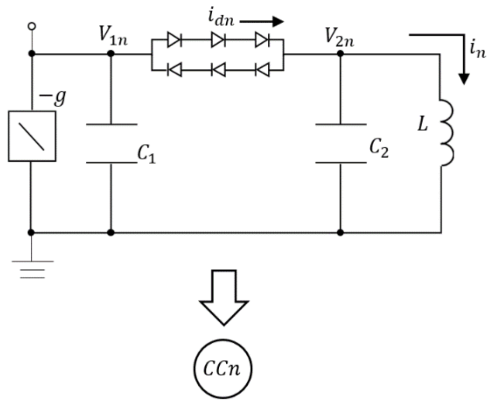

Figure 1: Circuits model.

$$\begin{cases} L\dfrac{di_1}{dt} = V_{2n}, \\ C_1\dfrac{dV_{1n}}{dt} = gV_{1n} - i_{dn}, \\ C_2\dfrac{dV_{2n}}{dt} = i_{dn} - i_n. \end{cases} \tag{1}$$

The normalized equation of this circuit is given as follows:

$$\begin{cases} \dfrac{dx}{d\tau} = z_n, \\ \dfrac{dy}{d\tau} = \alpha\gamma y_n - \alpha f(y_n - z_n), \\ \dfrac{dz}{d\tau} = f(y_n - z_n) - x_n. \end{cases} \tag{2}$$

The nonlinear function f() corresponds to the i-v characteristics of the nonlinear resistor consisting of the diodes and are described as follows:

$$f(y_n - z_n) = \begin{cases} \beta(y_n - z_n - 1) \quad (y_n - z_n > 1), \\ 0, \quad (|y_n - z_n| < 1), \\ \beta(y_n - z_n + 1), \quad (y_n - z_n < -1). \end{cases} \tag{3}$$

III. SYSTEM MODEL

This complex network is designed that each node has two or more links except for one node with scale free property. Only three nodes are set to the hubs (CC18, CC19, CC20). All coupling strength value are fixed with a certain rule. This rule is based on the different degrees between nodes. The value of coupling strength is determined by the number of degree of the node. Namely, the coupling strength is set to the certain value by calculating the difference of number of degree between the nodes and add 1.0 for every links.

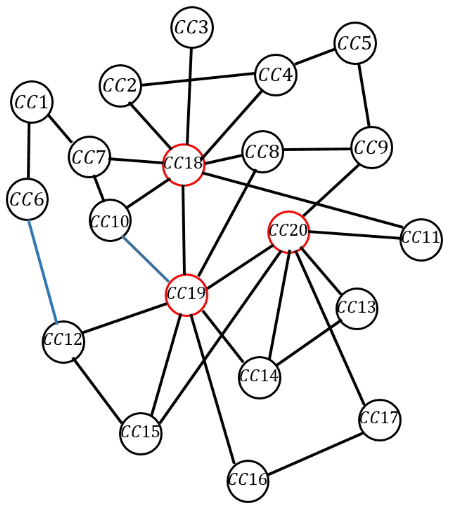

Figure 2: Network model.

IV. SIMULATION RESULT

In order to analyze synchronization states, we define the synchronization by the following equation.

$$|y_j - y_i| < 0.03 \qquad (i, j = 1, 2, \cdots, 10) \tag{4}$$

First, we investigate the synchronization by changing the coupling strength. Figure 3 shows the synchronization rate with the coupling strength.

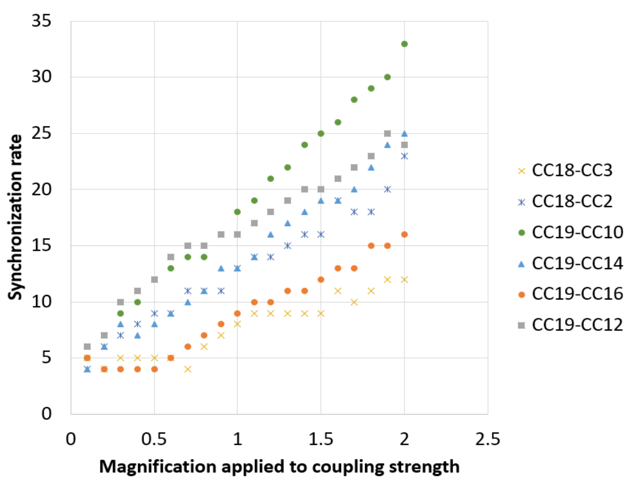

Figure 3: Synchronization rate of same strength link.

From this result, we confirm that the synchronization state is affected not only direct coupling but also indirect coupling. Next, we focus on the link of CC18 and CC19. The synchronization between CC18 and CC19 is measured when only CC10 - CC19 is opened or when only CC6 – CC12 is opened.

Table 1: Synchronization rate with open one link

Location of open link	*CC10-CC19*	*CC6-CC12*
Synchronization rate of CC18-CC19 [%]	46	36

The number of circuits between the two nodes is different for the both cases of open link (CC10-CC19 and CC6-CC12). Table 1 shows the result of synchronization rate when one link is opened. We confirm that the synchronization rate has higher value when the link between CC10-CC19 is opened.

V. CONCLUSION

In this study, we have investigated influence of path by using scale-free coupled chaotic network by changing the coupling strength. In this result, we found an effect of the path and coupling strength. Next, we have investigated synchronization between hubs when one indirect link is opened. We confirm that the effect of the coupling strength on synchronization is larger than the effect of the open link.

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