A NEURAL NETWORK MODEL TO CONFIGURE MAPS FOR A SATELLITE COMMUNICATION NETWORK†

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Abstract

In this paper, we describe a self-configurable satellite communication network which can be dynamically configured to different maps to best meet the network requirements by means of a modified Kohonen's self-organization. Our model consists of three stages. The first stage is the pattern recognition task which selects an exemplar map that best meets the current network requirements. The second stage analyzes the discrepancy between the chosen exemplar map and the state of the network, and adaptively modifying the chosen exemplar map to conform closely to the network requirement (input data pattern) by Kohonen's self-organization. Based on certain performance criteria, whether a new map is generated to replace the original chosen map is decided in the third stage. Experimental results are presented to demonstrate that our self-organization model can dynamically configure maps for a satellite communication network.

1. Introduction

The objective of traffic management is to best meet the communication requirement of users under the constraint of a fixed network capacity. That is, the probability of having users blocked from accessing the network should be the minimum. The reasons for the continuing effort and interest to come up with new management schemes to meet the advances of communication systems are:

(1) Since the invention of the telephone a century ago, the telecommunication network required to interconnect users at different locations on the globe has been growing steadily. With the advent of technological advances such as Broad-band Integrated Services Digital Network (*B-ISDN*) [1-3] the network which will meet the demand of high volume data exchange is very complexed. Managing the traffic of such a network is an engineering challenge.

(2) Due to huge investment in communication facilities, a slight improvement in the operation efficiency would result in considerable savings.

(3) The existing network is designed to operate under estimated average busy hour condition. By its very nature, the system is subject to demands over which it has or no control.

2. Motivation

Usually, routing methods are used to manage traffic of a network under a fixed configuration [4-7]. A satellite communication network, as opposed to the rigidity of a terrestrial communication network, is flexible and can be configured to various maps. Neural networks can naturally be applied to configure a satellite communication network adaptively. To take advantage of the flexibility of a satellite communication network, we propose a new scheme to manage traffic of the satellite communication network. Our scheme consists of two levels. At the first level, we introduce a self-organization model to dynamically configure maps for the network. The second level is a routing algorithm which manages the traffic of the network under a fixed configuration. This paper will mainly address the first level management. The incorporation of the two levels represents our continuing effort to maximize the network efficiency, and, will be reported in the future.

There has been an upsurge of interdisciplinary research effort on neural networks in recent years. As a novel application, we introduce a method using self-organization to realize the network configuration task. We will describe the model in details, and present experimental results.

3. Satellite Communication Systems

Satellite communications are flourished from decades of research efforts in the field of radio communications with the aim to achieving the greatest coverage and capacity, at the lowest cost. For example, the dream of television transmission across the oceans was realized via the application of satellite communications at a cost of only 10-20% of that of the undersea cable communication.

A satellite communication system [8] consists of two parts:

(1) Space — satellite relay station.

(2) Earth segment — earth stations containing transmitters and receivers for transmission and reception of signals from satellites.

There are many kinds of satellite communication systems. Among them, the "geostationary orbit" system is the most popular system used in modern satellite communications. In a geostationary orbit system [10], a satellite at a particular height above the equator moves at a constant speed. It travels around the earth as fast as the earth self-rotation. Thus, the satellite appears stationary to an observer on the ground. This makes the earth station equipment much simpler, because complexed synchronization mechanism is not needed. On the other hand, additional cost may be incurred to keep the satellites in the orbit because geostationary satellites are usually located at higher altitudes.

The main unique properties of satellite communications which distinguish them from terrestrial communication systems are:

(1) The broadcast property: a satellite transmission can be received at any point in its coverage area. In principle, three satellites are sufficient to cover the whole earth.

(2) Geographical flexibility: unlike terrestrial services, satellite transmission paths or networks built around them are not restricted to any fixed particular configuration—as they would be by a predefined pattern

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of underground cables or microwave systems. Within their area of coverage, satellite networks offer an infinite choice of routes.

(3) Distance-Insensitive costs: the cost of building and maintaining terrestrial transmission facilities is directly proportional to the length of the circuit or transmission route. Because the information travels through a free medium (space), satellite services is not so.

4. Terminologies

In satellite communications, time division multiple access (*TDMA*) is a multiple access technique used in digital satellite communication. It enables a number of earth stations to share a satellite's capacity by allocating each earth station a time slot to communicate. The network has a mesh topology which allows direct station-to-station communication. The communication established between two stations is known as a *communication link*. The capacity of each link is determined by the number of channels assigned to the link. The total number of channels allocated to each link in the network thus defines the capacity of the network.

We define the load and demand of a network as the state of the network. The state of the network is quantified by the number of channels demanded for each link of the network. The capacity of the whole network is a constant, but the numbers of channels allocated to each link should vary according to the state of the network. An assignment of channels to links within a network topology is called a *map*, as shown in Figure 1.

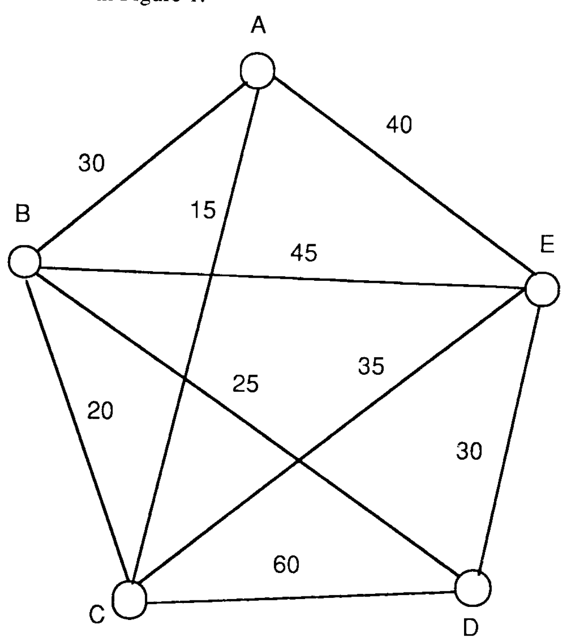


Figure 1. A map of a satellite communication network which has a mesh topology with 5 nodes and 9 links.

5. The Self-organization Model for Configuring a Network

Neural Network models have been studied for many years hoping to achieve human-like performance in various tasks. Speech and image recognition are the two main areas. Self-organization [13-14] is one of the neural network models that has been widely studied and applied to the industries.

Self-organization is an adaptive algorithm. Unlike traditional Least Mean Squares (*LMS*) algorithm [15], desired outputs are not specified. Data are entered sequentially and continuously to the self-organization model. After enough input data have been presented, the self-organization model will continuously cluster these data to produce outputs such that the probability density function of output clusters approximate the probability density function of the input data [13].

5.1. Our Approach

In the past, digital satellite communication network (without Demand Assignment Multiple Access device) is configured to different maps either according to a programmed time table or via an experienced human operator monitoring the state of the network. Demand Assignment Multiple Access (*DAMA*) [10] is a technique which allows the channel assignment of the network to vary slightly according to the change of the traffic in the satellite communication network. The DAMA scheme searches for idle channels from the network randomly and returns the channels to the network after communication services have been completed. They do not concern with the whole network efficiency and traffic lose. Our method will adaptively automate the "channel assignment" of the satellite communication network in order to achieve high network efficiency.

We pose the "channel assignment" problem of the satellite communication network as a pattern recognition and generation problem. During the network operation, the state of the network fluctuates constantly. We initially select N exemplar maps to which the network can configure. Each exemplar map is a map which can accommodate a typical demand of the network for a certain period of time during the network operation. We assume the exemplar maps are either provided by an experienced operator of the network or can be derived from the network statistics. In our method, the state of the network is constantly compared to each of the exemplar maps — this defines the pattern recognition task. The chosen exemplar map is adaptively changed according to certain performance criteria. That is, depending on how close the state of the network is matched to each of the exemplar maps, one of the following three actions will be taken:

(1) The original exemplar map which resembles the state of the network is retained.

(2) A different exemplar map which resembles the state of the network is selected.

(3) A new map is generated to replace one of the existing maps if the state of the network is remotely different from any of the existing exemplar maps for a long period of time.

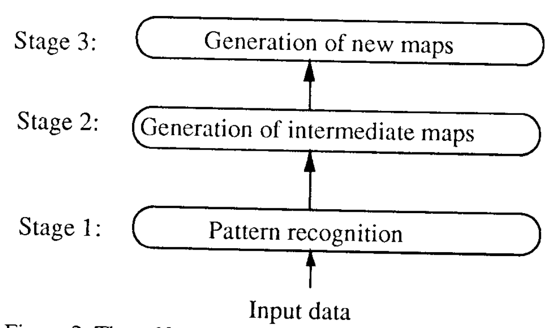


Figure 2. The self-organization model.

5.2. The Model

The self-organization model (*S-O* model) consists of three stages as shown in Figure 2. The first stage performs the pattern recognition task. In this stage, the self-organization model determines the exemplar pattern (map) which resembles most closely to the input data. The input data represent the state of the network. The second stage analyzes the discrepancy between the chosen exemplar map and the state of the network, and generates intermediate maps which gradually deviate from the exemplar map and converge closely to the input data pattern. A new map is finally generated by the third stage.

Denote L as the total number of links in a network,
T as the total number of channels in the network,
$R_i(t)$ as the number of channels in link i required by users at time t, and
$C_{ij}(t)$ as the total number of channels assigned to link i of the jth exemplar map at time t. Here, the parameter t indicates that exemplar map j is time varying.

We assume that the original N exemplar maps are given. We also assume that the state of the network is updated constantly from the Common Signaling Channel (*CSC*) [10] of the satellite communication system, and converted to numerical values denoted by $R_i(t)$. To perform the recognition task, the state of the network, $R_i(t)$, is updated as input data to the first stage of the S-O model. The S-O model computes the distance (metric) between the input data, $R_i(t)$, and each of the exemplar maps as follows:

$$D_j(t) = \sum_{i=1}^{L} |D_{ij}(t)|, \quad (j=1,2,...,N), \qquad (1)$$

where

$$D_{ij}(t) = R_i(t) - C_{ij}(t), \quad (i=1,2,...,L \text{ and } j=1,2,...,N).$$

$D_{ij}(t)$ indicates the busyness of link i in the network if exemplar map j is used. $D_{ij}(t)>0$ implies that link i of the network is overloaded when map j is used; i.e., channels allocated to link i of map j do not meet those demanded by the users in link i. $D_{ij}(t)<0$ means that link i of map j provides more than enough channels required by the users in link i. $D_j(t)$ thus indicates the resemblance between the input data $R_i(t)$ and exemplar map j.

Furthermore, instead of using $D_j(t)$, we use the normalized distance, $\overline{D}_j(t)$, as our metric, where

$$\overline{D}_j(t) = \sum_{i=1}^{L} |D_{ij}(t)|/R_i(t), \quad (j=1,2,...,N), \quad (2)$$

The normalized distance is used so that the pattern recognition task will select the exemplar map which distributes the load of the network *most evenly*. The exemplar map that best meets the requirement of the network is the one that yields the smallest normalized distance, $\overline{D}_j(t)$. This metric is only used in the pattern recognition task to select an exemplar map that resembles the state of the network most closely. It is the second stage which will self-adaptively change the chosen exemplar map to conform to the trend of the input data (the fluctuating state of the network).

The exemplar map selected by the first stage of the self-organization model may not satisfy the requirement of the network. If the chosen exemplar map meets the network requirement, that is, $\overline{D}_j(t)$ is small, we do not modify the map. If the chosen map does not satisfy the network requirement, we proceed to the second stage. It is the task of the second stage to modify the exemplar map to better meet the requirement of the network. Note that only the exemplar map selected by the first stage is modified. We call the resulting modified map produced by the second stage an *intermediate* map. This process is governed by the following equation, similar to Kohonen's self-organization [13]:

$$C'_{ij}(t+1) = C'_{ij}(t) + \beta(n(j))D'_{ij}(t), \quad (i=1,2,...L \text{ and } j=1,2,..N) \qquad (3)$$

where $D'_{ij}(t) = R_i(t) - C'_{ij}(t)$.

$C'_{ij}(t)$ is the number of channels of link i of map j which is being modified, and $\beta(n(j))$, $0<\beta(n(j))<1$, is a gain factor. Here, we use "prime" to distinguish the map which is being modified in the second stage from the original exemplar map chosen in the first stage. The modified map generated in the second stage may or may not replace the original exemplar map — this is determined by the third stage. As map j is being modified, $D'_{ij}(t)$ indicates the busyness of link i of the modified map j. $D'_{ij}(t)>0$ implies that link i of the network using the modified map j is overloaded; i.e., channels allocated to link i of the modified map j do not meet those demanded by the users in link i. $D'_{ij}(t)<0$ means that link i of the modified map j provides more than enough channels required by the users in link i. n(j) is the number of occurrence of exemplar map j being selected. When a new exemplar map j is generated by the third stage, this number is reset to 0. $\beta(n(j))$, is a monotonically decreasing function. We use:

$$\beta(n(j))=k_1^{-(n(j)+k_2)}. \qquad (4)$$

The gain factor $\beta(n(j))$ has three effects. It affects the drift of map j being modified to converge to the input pattern. It also determines whether a new map j will be generated in the third stage, which will be discussed shortly. Finally, it affects how fast a new map is generated.

In the third stage of the S-O model, we compute a convergence factor, E(j), to decide whether a new map should be generated to replace the exemplar map. We define

$$E(j) = \max_i \{| \beta(n(j))D'_{ij}(t)|\} \quad (i=1,2,...L) \quad (5)$$

From Equations (4) and (5), E(j) is getting smaller when the jth map has been selected more often, indicating that the modified (intermediate) map j is reaching more closely to the network requirement. E(j) indicates how close the modified map j is to the required load. A new map is thus generated based on the following conditions:

If $E \geq r$, $\quad C_{ij}(t+1) = C_{ij}(t) \quad (i= 1,2, ...L) \quad (6)$

Else, $\quad C_{ij}(t+1) = C'_{ij}(t), \quad$ for $B \leq T$, $\quad (7)$

or $\quad C_{ij}(t+1) = \frac{T}{B} C'_{ij}(t), \quad$ for $B \geq T$, $\quad (8)$

where

$$B = \sum_{i=1}^{L} C'_{ij}(t).$$

B is the total number of channels assigned to the modified map j at time (iteration) t, and r is the threshold set to define whether a new "channel assignment" is made. T, as defined earlier, is the capacity of the whole network.

From Equations (4), (7) and (8), if the jth map has been selected often enough (i.e., $\beta(n(j))$ is small enough to make E less than r), the self-organization model generates a new map j to replace the original chosen exemplar map. If the capacity of the modified map exceeds the capacity of the network, the modified map is normalized as shown in Equation (8).

6. Experimental Results

We simulated various satellite communication networks with different number of links and capacity. All results are similar. As an example, we present a simulation of a satellite communication network with 10 links and a capacity of 1000 channels. Ten original exemplar maps are given and shown in Table 1. Figure 4 shows the simulation results. It shows the number of channels required by users and the channels assigned by the algorithm as a function of time for each link of the network. The network requirement fluctuates slightly (random data), from t=1 to t=199, and changes drastically at transition t=200, and then varies slowly until t=500. The jagged line in each graph indicates the requirement for the link as a function of time t, and the lower smoother line is the number of channels that the self-organization model suggests to provide for that link. In the simulation, the demand of the network is larger than the capacity. The channels assigned by our algorithm, under the constraint of a fixed capacity and overloaded network, follow the trend of the demand closely.

Map No.	Link									
	1	2	3	4	5	6	7	8	9	10
Map 1	100	100	100	100	100	100	100	100	100	100
Map 2	120	80	120	80	120	80	120	80	120	80
Map 3	130	70	130	70	130	70	130	70	130	70
Map 4	150	50	150	50	150	50	150	50	150	50
Map 5	120	110	100	120	110	100	80	90	100	70
Map 6	80	90	100	80	90	100	120	110	100	130
Map 7	70	85	135	70	85	135	110	100	90	120
Map 8	60	140	100	60	140	70	110	110	120	90
Map 9	40	60	200	40	60	100	100	100	200	100
Map10	140	60	140	60	140	60	200	0	200	0

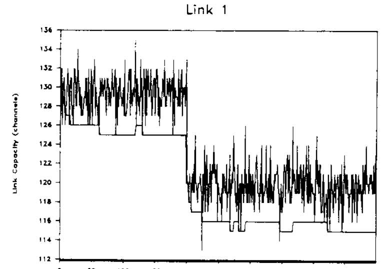
Table 1. Ten exemplar maps, each with 10 links and a capacity of 1000 channels.

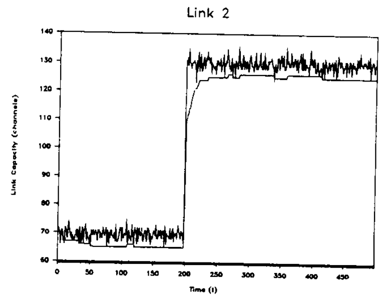
7. Conclusions

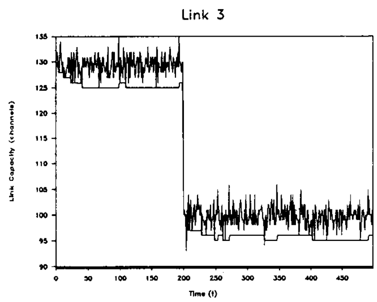
We have presented a simulation which demonstrates that our approach is able to configure maps for a satellite communication network dynamically. In the simulation, the network is overloaded. The overloaded condition is the most serious situation from the network traffic management point of view. The channels are assigned by our approach to maximize the network efficiency. Usually, if the load is less than the capacity of the network, the network control center may use the traditional routing algorithm to manage the traffic. When the average waiting time for each call or package is high enough, the network control center should use the self-organization model to reassign the number of channels allocated to each link. Thus, the self-organization model is used at a higher management level, controlling the traffic briefly, and traditional routing algorithms are used at a lower level, routing the traffic via various paths. We are currently working to incorporate optimal routing and queueing algorithm [4] with our algorithm to improve network efficiency.

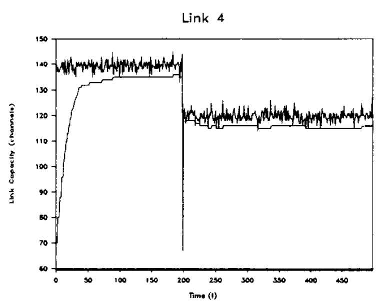
8. References

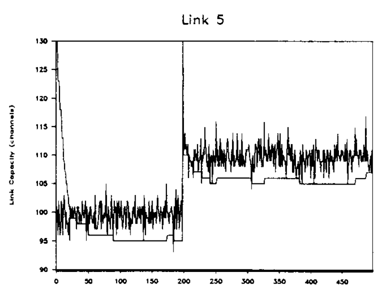
1. H. Yamaguchi, "Views on Future Telecommunications Services and Technologies," *NTT Review*, Vol.1, No.10 (May 1990), pp.6-15.
2. K. Murano, K. Murakami, E. Iwabuchi, T. Katsuki and H. Ogasawara, "Technologies towards Broadband ISDN," *IEEE Communications Magazine*, Vol.28, No.4 (1990), pp.66-70.
3. M. Frame, "Broadband Service Needs," *IEEE Communications Magazine*, Vol.28, No.4 (1990), pp.59-62.
4. G. R. Ash and V. S. Mummert, "AT&T Carves New Routes in its Nationwide Network," *AT&T Bell Laboratories Record*. No.10 (August, 1984), pp.102-106.
5. G. R. Ash, "Use of a Trunk Status Map for Real-Time DNHR," *International Telephone conference -11* (1985), pp. 56-72.
6. G. R. Ash, "Building a Dynamic Routing Architecture," *Telephone*, Vol.5, No. 6 (June 27, 1983), pp. 42-51.
7. B. R. Hurley, C. J. R. Seidl and W. F. Sewell, "A Survey of Dynamic Routing Methods for Circuit-Switched Traffic," *IEEE Communications Magazine*, Vol.25, No.9 (1987), pp.13-21.
8. G. B. Bleazard, *Introducing Satellite Communications* (England: NCC publication, 1985).
9. Kamilo Feher, *Satellite/Earth Station Engineering* (Englewood Cliffs: Prentice-Hall, 1983)
10. T. Pratt and C. W. Bostian, *Satellite Communication* (New York: John Wiley & Sons, 1986).
11. D. W. E. Rees, *Satellite Communications: The First Quarter Century of Service* (New York: John Wiley & Sons, 1990).
12. D. Chakraborty, "VSAT Communications: An Overview," *IEEE Communications Magazine*, Vol.26, No.5 (1988), PP.10-24.
13. T. Kohonen, *Self-Organization and Associative Memory* (Berlin: Springer-Verlag, 1984).
14. R. P. Lippmann, "An Introduction to Computing with Neural Nets," *IEEE ASSP Magazine*, Vol.4, No.2 (April, 1987), pp.4-22.
15. B. Widrow and S. D. Stearns, *Adaptive Signal Processing* (Englewood Cliffs, NJ: Prentice-hall, 1984).

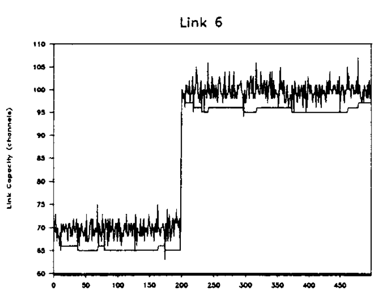


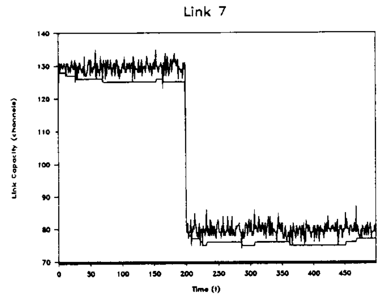


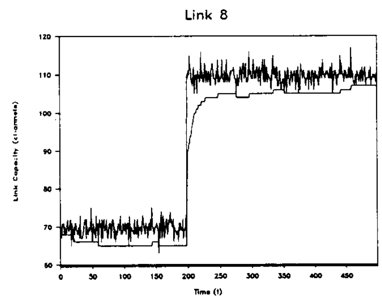


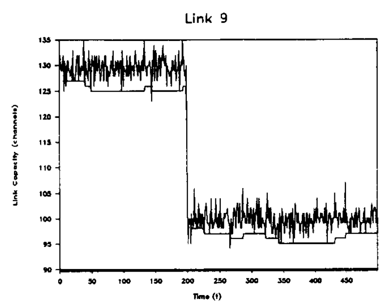












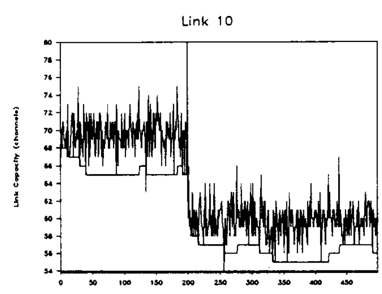


Figure 4. The results of applying our algorithm to the simulated network with 10 links and a capacity of 1000 channels. The jagged line in each graph indicates the requirement for the link, and the lower smoother line is the number of channels that our model suggests to provide for that link, both versus time.