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Abstract

Cycle-based routing is an efficient routing mechanism widely used to achieve fault-tolerant, reliable, and robust network routing. To meet all-to-all source-destination pairs traffic requirements using cycle-based routing, one efficient method is to use quorum sets to establish cycles to serve each source and destination pair on one of the cycles. Quorum-based cycle routing significantly reduces the total number of direct links to be used in the network compared to establishing all point-to-point communication routes. Adopting different quorum sets provides similar flexibility and reliability yet yields significant differences in resource utilization. We compare multiple quorum sets to establish cycle-based routing paths. We then adopt average cycle length (ACL), standard deviation of cycle length (SDCL), and longest cycle length (LCL) of different configurations of cyclic quorum sets as performance metrics. Using NSFnet topology, we conclude that there is no perfect cyclic quorum set that yields optimal performance for all metrics, and trade-offs need to be made based on the most significant network design requirement when choosing a solution.

Keywords

Cycle-based routing, all-to-all communication, quorum-based cycle routing, cyclic quorum sets application

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Establishing Efficient All One-to-One Paths by Exploring Cyclic Quorum Sets

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***Abstract*—Cycle-based routing is an efficient routing mechanism widely used to achieve fault-tolerant, reliable, and robust network routing. To meet all-to-all source-destination pairs traffic requirements using cycle-based routing, one efficient method is to use quorum sets to establish cycles to serve each source and destination pair on one of the cycles. Quorum-based cycle routing significantly reduces the total number of direct links to be used in the network compared to establishing all point-to-point communication routes. Adopting different quorum sets provides similar flexibility and reliability yet yields significant differences in resource utilization. We compare multiple quorum sets to establish cycle-based routing paths. We then adopt average cycle length (ACL), standard deviation of cycle length (SDCL), and longest cycle length (LCL) of different configurations of cyclic quorum sets as performance metrics. Using NSFnet topology, we conclude that there is no perfect cyclic quorum set that yields optimal performance for all metrics, and trade-offs need to be made based on the most significant network design requirement when choosing a solution.**

***Index Terms*—Cycle-based routing, all-to-all communication, quorum-based cycle routing, cyclic quorum sets application.**

I. INTRODUCTION

Fiber-optic network has become a prevailing option for modern backbone infrastructure delivering consistent reliability and performance. To address the realization of a fully connected topology, cycle-based routing has been proved as a potential efficient solution in networks such as SONET [1]. Each pair of nodes is served using an identified path on one of the cycles where both source and destination reside. Cycle-based routing can also provide protection using a pre-configured p-cycle [2] backup path.

To set up cycles, Cory et al. adopted a quorum-based method to provide 100% single for each source-destination pair. They extended the cycle-based routing to provide redundant paths between each-source destination pair using unidirectional cycles using redundant. They proved that $96.6\% - 99.37\%$ fault coverage can be achieved for any single physical link failure and redundant cycle use $42.9\% - 47.18\%$ fewer resources in [3]. They showed that cyclic quorums sets have all-pairs property and there can be more than one cyclic quorum set for a given set of nodes. Thus, a natural relevant question to ask is which cyclic quorum set provides a better routing strategy for a given network topology. We explore and answer this question in this paper.

A. Contributions

We report the following major contributions.

- We observe significant resource utilization difference when adopting cyclic base sets for network routing.
- We compare all pair routing solutions using three metrics, average cycle length (ACL), standard deviation of cycle length (SDCL), and longest cycle length (LCL), of different configurations of cyclic quorum sets. We show that trade-offs need to be made according to the most significant network design requirement.

B. Outline of the paper

Section II provides prerequisite knowledge of cyclic quorum sets and shows its routing efficiency. Detailed results using selected cyclic quorum base sets, routing cycles and their statistical analysis are provided in section III. We conclude the paper and discuss future research directions in Section IV.

II. Cycle Routing Using Cyclic Quorum Sets

A cyclic quorum set is a group of p base sets with a property that once one of them is known, all other base sets can be derived using that set in a cyclic manner. One example is provided in Fig. 1. For simplicity, cyclic quorum sets will be referred to as CQS in the rest of the paper.

In computation problem, to realize all-pairs interactions among N elements in a distributed manner with p processors, we can divide N elements into p data subsets, D_i for $i = 0, 1, ..., p-1$, each with a size of $\frac{N}{p}$. They are initially distributed and each processor receives subset corresponding to indices of elements of S_i. A processor performs all-to-all interactions among assigned subsets. An optimal CQS guarantees the union of local results covers all possible interactions. One feature of CQS is that after data distribution, all pair interactions can be computed without further communication.

Applying CQS to communication problem, we set $N = p$, as the interaction between two nodes in a graph is equivalent to establishing a point-to-point communication path between them. Each D_i can be viewed as a single node and the base set S_i includes the nodes that must appear on one cycle. One example of optimal CQS where $p = 7$ is depicted in Fig. 1 that can be used in both computation and communication perspectives. Using the property that all pair interaction happen among in the CQS, we only need to establish links among nodes within each set to establish communication paths between all node pairs. Therefore, the greatest benefit of quorum-based routing over traditional point-to-point connection is a much smaller total number of links.

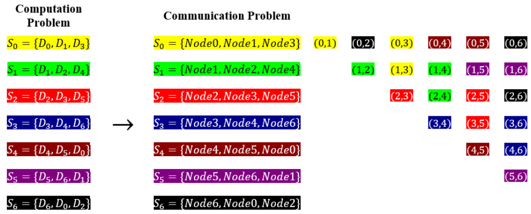

Figure 1: An optimal CQS for all-to-all (i) data interaction or (ii) communication paths computation (color coordinated).

In cycle-based routing, both source and destination are embedded on the same cycle. In this paper, we show the cycle routing efficiency of CQS using a well-known topology called NSFnet. It has 14 nodes and 22 bidirectional edges as shown in Fig.2. Any source node could have traffic to pass on to any other node through pre-established paths [3]. As there are 91 possible node pairs yet only 22 direct links, to support all-to-all communication, it requires over 200 links adopting traditional point-to-point connections.

Applying CQS routing, specifically with the base set $S_0 = \{0, 1, 2, 3, 7\}$, it requires only 120 links to enable all-to-all communication as proved in [3]. We wonder if applying other base sets will result in performance difference. To investigate this question, we cast experiment with six different base sets and the details are discussed in Section III.

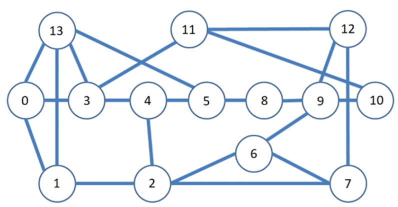

Figure 2: NSFnet topology with 14 nodes and 22 links

III. Results

In NSFnet, there are 14 nodes, thus, $p = 14$ and the size of quorum set(n) is 5. Here we pick six random feasible CQS base sets, as listed in the first column of Table I. For the whole CQS, we determine the shortest cycle in NSFnet using the ECBRA heuristic algorithm developed in [4]. We carry out statistical analysis on cycle lengths and interpret the results.

The routing results of base set $\{0, 1, 2, 3, 7\}$ are in Table II and the rest sets are studied in the same way. We analyze in terms of average cycle length (ACL), standard deviation of cycle length (SDCL) and longest cycle length (LCL).

Shorter ACL means there is less cost in time and energy to transmit data and fewer components could be faulty. Smaller value of SDCL suggests the system is more balanced because it is less likely that there is an extremely long cycle that hurts the overall performance badly. However, it is possible that a CQS has a shorter ACL yet greater SDCL. The absolute value of LCL matters. It is the real bottleneck. Comparisons among six base sets are presented in Table II.

Quorum	Cycle	Length
(0, 1, 2, 3, 7)	0 1 2 7 12 11 3	7
(1, 2, 3, 4, 8)	1 2 6 9 8 5 4 3 13	9
(2, 3, 4, 5, 9)	2 4 3 13 5 8 9 6	8
(3, 4, 5, 6, 10)	2 4 5 13 3 11 10 9 6	9
(4, 5, 6, 7, 11)	2 4 5 13 3 11 12 7 6	9
(5, 6, 7, 8, 12)	2 4 5 8 9 11 12 7 6	8
(6, 7, 8, 9, 13)	1 2 7 6 9 8 5 13	8
(7, 8, 9, 10, 0)	0 1 2 7 12 11 10 9 8 5 13	11
(8, 9, 10, 11, 1)	0 1 13 5 8 9 10 11 3	9
(9, 10, 11, 12, 2)	2 6 9 10 11 12 7	7
(10, 11, 12, 13, 3)	1 2 7 12 9 10 11 3 13	9
(11, 12, 13, 0, 4)	0 3 11 12 7 2 4 5 13	9
(12, 13, 0, 1, 5)	0 1 13 5 8 9 12 11 3	9
(13, 0, 1, 2, 6)	0 1 2 6 9 8 5 13	8
		Avg: 8.57

Table I: Embedding of CQS $\{0, 1, 2, 3, 7\}$

Interest set	**ACL**	**SDCL**	**LCL**
{0, 1, 2, 3, 7}	8.57	1.016	11
{0, 1, 8, 12, 13}	8.57	1.116	11
{0, 1, 3, 10, 11}	8.79	1.145	11
{0, 1, 4, 5, 12}	8.64	1.042	10
{0, 1, 3, 5, 7}	9.57	1.178	13
{0, 1, 5, 7, 10}	9.14	1.505	11

Table II: ACL, SDCL and LCL comparison

Results show that the difference of CQS cannot be ignored. Moreover, there is no CQS that stands out in all dimensions. That means trade-offs should be made according to the desired feature of a system during design. The shortest ACL we found so far is 8.29. However, it has the greatest SDCL, 1.623 and a moderate LCL of 11, which shies it from the best CQS while reinforces our conclusion that no base set is perfect in every aspect.

IV. Conclusion

With all feasible base sets provided, different CQS can be applied to solve node communication problem more efficiently. We would like to explore more advantages of base sets apart from its fault-tolerant and resource saving features. In the future, we are exploring a way to precisely locate the base set with the multiple desired characteristics to help networking topology design.

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