An Extended Platter Metaphor for Effective Reconfigurable Network Visualization

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Abstract

We adapt the Flodar [6] metaphor to visualize dynamic networks and present experimental results on the effectiveness of this approach. Dynamic reconfiguration of networks enable rapid optimization of performance of a network, however, it poses several management difficulties when user intervention is required to resolve complex routing problems.

Our metaphor scales well for networks of varying size, addresses the cluttering problem seen in past metaphors and maintains the overall network context while providing additional support for navigation and interaction. We apply the metaphor to three dynamic reconfiguration management tasks and show how these tasks are visually represented with our approach.

We conducted an experiment with network administrators and researchers as subjects. A good understanding of network conditions portrayed in the metaphor was achieved within a short period.

1. Introduction

We use visualization to address management problems in dynamic high-speed networks. Traditional network management tools are largely designed to serve static networks and emphasize packet flow and node connectivity [1] [2] [3] . Because dynamic reconfigure-tion is constantly changing the logical network routes, it is difficult to understand the interactions between changing traffic demands and the logical connections on which they are carried [4] below[5] .

Our contribution includes a visualization metaphor to aid understanding connectivity changes in dynamic networks. We want greater understanding of resource management algorithms and their impact on networks. We developed and tested our network metaphors on the data generated by our dynamic network simulation; and evaluated the effectiveness of our approach with a questionnaire-based subjective experiment.

Our platter metaphor is an extension of the original metaphor used in the Flodar application [6] to include changes to node layout, categories of network information and scalability. Our metaphor does not address spatial layout, since this is not relevant and spatial metaphors suffer from clutter for large networks. We are also not aiming to build a complete management tool such as CyberNet [7] but choose to address certain key issues with a single metaphor.

We represent information about 'origin-destination' pairs as the following properties change dynamically:

- *Capacity distribution*
- *Capacity versus route length distribution*
- *Route distribution*

The rest of this paper will focus on the visualization metaphor and will not deal with the network properties themselves but we review some concepts below.

Necessary Network Concepts: Communication channels are no longer limited to a fixed data rate: an application uses only the bandwidth required. Networks cater for various traffic services and can guarantee a *Quality of Service* (QoS) for individual traffic services. Underlying a network are *virtual path connections* (VPCs) which form logical direct end-to-end connections between all *origin-destination* (OD) pairs (Figure 1). These end-to-end connections create fully meshed logical networks or v*irtual path connection networks* (VPCNs) upon sparse physical networks [8] . It is possible to adjust the routes and bandwidth of

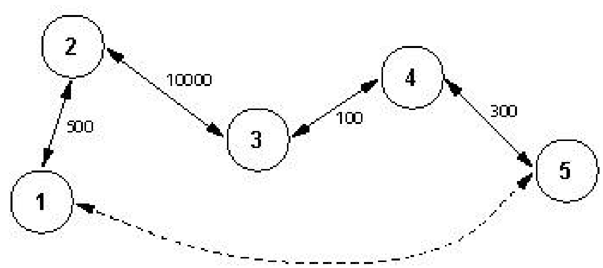

Figure 1. Origin-Destination (OD) Pair (1-5) with Path (1-2-3-4-5): Physical links (with capacities) are solid lines; virtual (OD) pairs are dashed lines; circles represent nodes. This route belongs to an OD (1-5) and has a unique identifier with a path and capacity unit in our application.

VPCs dynamically in near real time in order to maintain an optimally designed VPCN. Network resource management adjusts the logical link capacities to size the virtual path optimally whenever conditions demand.

2. The Platter Metaphors

The metaphor chosen had to fulfill the following requirements:

- *High Frequency and High Volume Dynamic*

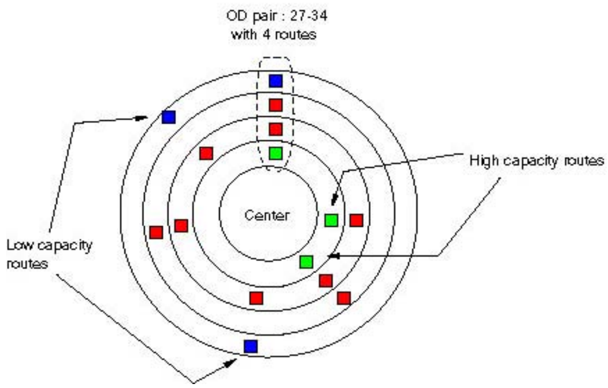

Figure 2. The Platter Metaphor from the Top: each pillar represents a route with capacity. Routes of the same OD pairs align to form a spoke from the centre to the edge. The capacity of each route is indicated by its proximity to the centre.

  Reconfiguration:
  Reconfigured routes may undergo several transformations to maintain service levels: changes in capacity, extermination or introduction of logical routes. Routes and capacities are updated frequently while origin-destination pairs are updated infrequently.

- *Scalability in Network Size.*
  Traditional 2D metaphors (e.g., network map) are prone to exhibit *display cluttering*. 3D metaphors may exhibit less cluttering but the problem of *occlusion* is introduced.

- *Interactive Updates:*
  Primitives should allow fast rendering and navigation through the data.

Our *platter* metaphor is an adaptation of the Flodar [6] application which was developed for identifying unresponsive network servers (Figure 2). We adapted the platter metaphor to accommodate support for OD pairs and routes and large scalable networks. We primarily used concentric rings from the centre to indicate capacity. The capacity at the edge of the platter is zero for most management applications (or some other minimum capacity); the capacity in the centre of the platter can represent a user-defined maximum.

Routes are represented as a pillars (i.e., geometrically cylinders or cubes) on the platter while their capacity is encoded by its closeness or proximity to the platter centre (here the height of each pillar didn't encode network information). We took this decision because the height of an individual pillar closer to the edge of the platter could occlude pillars on the same orthogonal line from the edge to the centre.

An OD pair is represented by the arrangement of routes in a straight line projecting from the centre towards the edge of the platter (Figure 2 and Figure 6. Platter Metaphor and Information Window used in the experiment.). The image formed by multiple OD pairs resembles the arrangement of spokes in a wheel.

There are numerous advantages to this layout:

1. Clutter can be minimized by aggregating a number of routes into a single cylinder.
2. Route information can be represented using the height, radius and material properties of each cylinder.
3. The symmetrical design allows user to spot interesting trends and patterns at a quick glance.
4. Overall network context is maintained, allowing users to investigate individual OD pairs without losing other interesting network features.

Providing detailed information about individual routes is supported by the platter metaphor. When a user selects a route on the platter, information such as the capacity, logical route length, virtual path and the OD pair to which it belongs, is displayed. Initially, we used the material properties of each route cylinder and 3D text labels to provide the accompanying information. However, we discovered this had a significant impact of the rendering performance of the metaphor for large networks. Instead, we decided to include an information window which would display this information. This information window allows for additional control tools to support the metaphor.

Since the objects used in the platter are simple three-dimensional primitives, it scaled well for large network with many routes. No additional rendering support like level-of-detail and frustum culling was needed to display network configurations of up to 15,000 routes.

The platter metaphor demonstrated less cluttering and supported a full context view of the entire network. This was particularly useful for identifying patterns within the network.

Initial testing suggested that the platter metaphor was suitable for our primary applications based on feedback received from our dynamic network expert. We tested the metaphor's effectiveness across three management applications. These applications ranged from simple

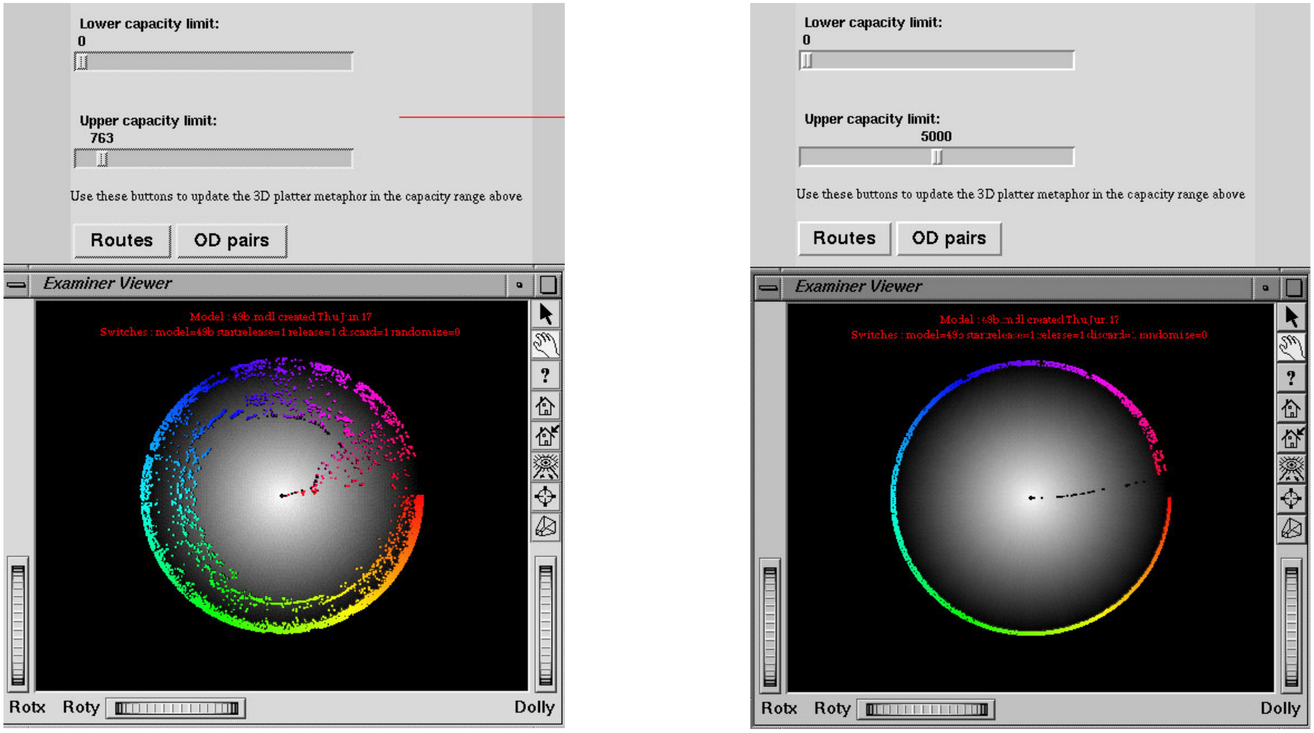

Figure 3. Platter Metaphor: Capacity Distribution between two reconfigured networks. Left — well-distributed routes with varying capacity. Right — a larger concentration of routes with low capacity. The former is more desirable.

network accounting on the number of routes to more complex applications such as displaying the distribution of capacity versus the route length in the network.

3. Management Applications

We have now motivated the general approach of using the platter metaphor. In the following sections we present several specific management tasks that are supported by the platter metaphor.

3.1. Application 1: Capacity Distribution

Effective routing is the centre of all operations in network management. The platter metaphor can provide information about the capacity distribution of the VPCN network as illustrated in Figure 3. The layout of route cylinders in each OD pair are used to indicate capacity trends in the network. This view enables administrators to gauge the distribution of capacity in the network. The layout of routes gives a concise indication that the majority of routes have low capacity since most routes lie near the edge of the platter. Colour was used to indicate OD pair affiliation.

This view is useful when administrative intervention is required to distribute capacity amongst routes. Attention can easily be drawn to routes which are close the centre of the platter. These routes consume a large portion of capacity leaving less capacity for the rest of the network. Through this view, administrators can easily identify routes with excessive capacity.

3.2. Application 2: Capacity *vs* Route Length

This application is similar to the capacity distribution view with colour used to indicate route length. This application is useful when evaluating the optimal route configuration after a network has undergone reconfiguration. Colour is used to indicate the number of links (i.e., logical route length) of each route. We used six colours to encode route lengths ranging from one to ten or more links. For example, red was used to indicate route lengths between one and three links while green encoded lengths between four and six. As in our previous application, the capacity of each route is encoded by its proximity to the centre. OD pair affiliation is still represented as a straight line from the edge to the centre of the platter.

This layout enables an administrator to view the entire network configuration and make informed decisions about the distribution of capacity amongst routes. From Figure 4 we observe that the majority of low capacity routes (i.e., routes near the edge) are green which implies a route length between four and six links. Based on this view, an administrator can observe when excessive capacity is assigned to long routes with a

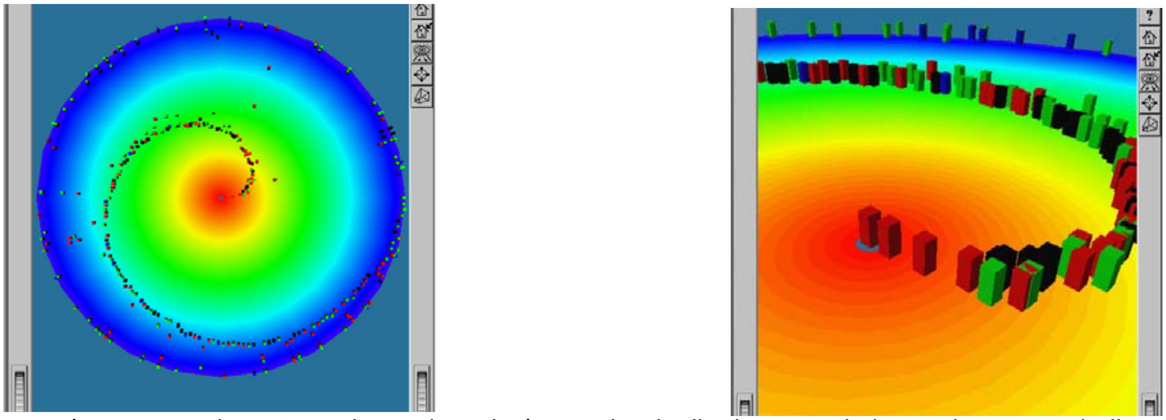

Figure 4. Platter Metaphor: Capacity and Logical Length Distribution. Proximity to the centre indicates the capacity while its colour indicates the number of links (i.e., length) in each route: Length legend: Red— 1–3; Green— 4–6; blue— 7–9. Administrators can determine whether the reconfiguration is assigning excessive capacity to potentially unstable and long routes. Left is an overview and Right is a close-up view. The spiral pattern indicates that route capacities are increasing as the routes approach the centre of the platter.

length of five or more links. By drawing their attention using the platter, an administrator can minimize susceptibility to connection failures by monitoring long routes with high capacities.

3.3. Application 3: Route Distribution

This view represents the number of routes in each OD pair. A good network configuration will result in a small number of routes, whereas a poor design will have a large number of routes in each OD pair. A small number of routes will have a higher capacity per route than a configuration with a large number of routes.

Figure 5 demonstrates the effectiveness of this view. Both figures are based on a network model given the same traffic load. They differ only with respect that configuration A had its routes chosen randomly when multiple routes existed between each start and destination nodes whereas configuration B uses predetermined routes. Both configurations are almost identical, which implies that both route strategies generate the same optimal network.

4. Testing the Effectiveness

Our metaphor was developed to aid in understanding dynamic network information, in particular:

- *support for reconfigurable networks*
- *accommodation of abstract network data*
- *ability to handle large and sparse networks*

In support of our metaphor design objectives, we need to determine the *usefulness* and *effectiveness* of this metaphor with respect to our application. To evaluate the effectiveness of this metaphor, we analysed

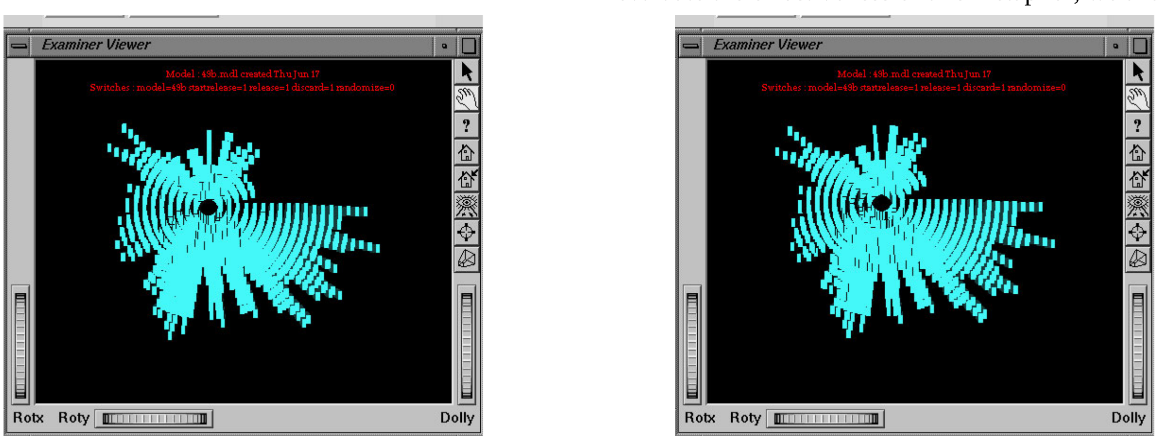

Figure 5. Platter Metaphor: Route Distribution. The left (A) and right (B) images show two different algorithms for route configuration. The difference between these networks is minimal and this indicates little difference in number of routes in an OD pair for both configurations.

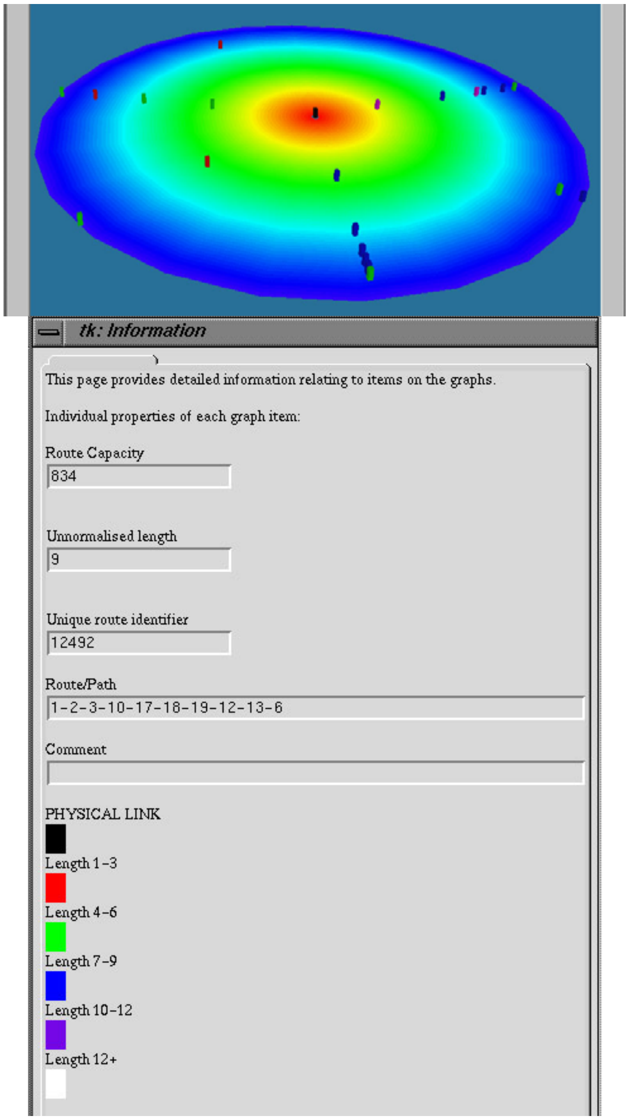

Figure 6. Platter Metaphor and Information Window used in the experiment.
Top—platter metaphor: bands from outside to inside represent an increase in capacity. Bottom — window for details about the route and its capacity.

the metaphor to determine how well it conveys our dynamic reconfiguration information. Two important metrics were investigated:

1. Time taken to learn and interpret the metaphor,
2. Correct interpretation and understanding of current network conditions.

We employed user testing to test and verify our assertions about the effectiveness of the metaphor. Users' responses to a questionnaire were recorded and analysed to measure their understanding of the current network configuration. The users were network researchers and administrators with experience or knowledge in network management or administration.

There were 14 experimental subjects, 4 were network administrators and the remainder were network research students. They were given a short tutorial explaining the concept of the metaphor and the network properties it represents. Following this tutorial, these subjects completed a network questionnaire designed to test their knowledge of the platter metaphor and its content. Questions were grouped into sections which required specific network knowledge:

1. Physical appearance of the metaphor
2. Quantitative network route information
3. Detailed information on individual network routes
4. Problem solving using network information contained in the metaphor
5. Administrative network decisions based on the information provided by the metaphor

Each section contained 4 questions except for Section 4 which had 3 questions.

The questions in Sections 1 and 2 were based on a set of images. These images were generated by our platter metaphor program. A subject was asked to investigate and identify network routes portrayed in each image. In response, the subject chose an appropriate response from the multiple-choice list.

Sections 3, 4 and 5 are based on a computer program using the platter metaphor. The subject will be asked to extract information from the metaphor using the three-dimensional navigation controls and an information widget (Figure 6).

Section 5 was treated as a special section since it required administrative knowledge to answer successfully. Each question in this section is either TRUE, FALSE or UNDECIDED.

4.1. Results

The mean score for all subjects was 80.08%. Subjects scored 83.8% for Sections 1 to 4 with a mean score of 66% for Section 5. Each section required network skills of varying degrees. These included simple accounting and quantification of network units to more complex network management problems including resolving abnormal network conditions.

We analysed the relationship between the Total Score and Network Experience. We tested whether experienced administrators have a higher total score than administrators with less experience.

This correlation revealed an unexpected negative r-correlation value of -0.66 ($r = -0.66$, $t = -3.04$, $p = 0.0102$). This is significant at a 95% confidence level. This result suggests that more experienced network subjects are less likely to have a higher total score. We discussed this correlation attempting to clarify the cause of this relationship in Section 4.2.

Timing results tested our hypothesis that the time taken to learn the metaphor is small. The mean total time for the experiment is 23.43 minutes. There was an increasing mean time progressing through successive sections. The mean total time is 23.43 minutes with a minimum of 14 minutes and a maximum of 59 minutes.

4.2. Discussion

As noted above we were initially surprised at a negative correlation between experience and score. We re-examined the results and found an outlier. One subject performed poorly in the questionnaire resulting in a total score of 21.03%. This subject had 10 years network experience. We removed this sample as an outlier and recomputed the Total Score *versus* Network Experience correlation. The new r-correlation value of 0.17 ($r = 0.16$; $t = 0.52$; $p= 0.61$) is *insignificant* at the 95% confidence interval.

We showed that less experienced administrators perform equally well in this experiment. We compiled an expected score range for suitably qualified network administrators, who had experience in configuring and administering such networks. From our questionnaire, we extracted the mean times and mean scores for sections requiring varying degrees of network management skills.

It was evident that the scores achieved by all the subjects for each section were within expected score ranges. This supports our suggesting that this metaphor aids the understanding of administrators and supports their management capabilities. In all sections, the mean time for each section scored by subjects is in our expected range. It shows that most subjects grasped the fundamentals of the experiment within 30 minutes.

The mean time to complete all networks tasks is 23.43 minutes. This is considered acceptable by today's standards. It is not uncommon to have network tools which require hours or days of training before subjects have adequate grasp of its functionality.

5. Conclusions

Our main contribution lies in a metaphor design to convey abstract network information in a concise and understandable manner. Our platter metaphor has overcome several drawbacks inherent in previous visualizations while aiding the understanding of complex dynamic changes in reconfigurable networks.

We ran user experiments with network administrators and researchers. The results confirm that our metaphor is effective in conveying network information and that this understanding is rapidly achieved.

The design of the platter enables efficient and easy monitoring, requiring less time to identify abnormal network conditions than interpreting textual log files generated by a dynamic network. It aids administrators particularly in understanding complex network relationships and connectivity changes. The experiment results also emphasized that the platter metaphor did not require expert administrative knowledge or extensive previous training in order to monitor our network management application.

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