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DYNAMIC ROUTING WITH LINK STATE INFORMATION IN ADNS AND FUTURE SATCOM NETWORK¹

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ABSTRACT

A future satellite communications system is envisioned that will provide a number of enhancements over predecessor satellite communication systems. It will employ high capacity packet switched service in space, high rate circuits between terminals, and utilize Dynamic Bandwidth Resource Allocation which dynamically assigns resources to terminals based on current channel conditions and traffic demand. However, to realize these potential benefits, we must be able to integrate the future satellite network seamlessly with the existing communication networks. In this paper, we assess the impact of variable rate satellite links on the existing communication network and propose possible solutions to mitigate the adverse impact. With no awareness of the variable rate uplink in the future satellite network, the data routed by the existing user network into the satellite network may be dropped at the edge of the two different networks due to a rate mismatch, or conversely, the satellite links may be underutilized. Here, our proposed method will prevent significant packet drop and make more efficient use of available links by dynamically rerouting traffic based on the real-time link capacity of the satellite network.

I. INTRODUCTION

The future SATCOM system is envisioned to support a diverse range of applications such as voice, data, video, broadcast, imagery, and multicast services for users. It will provide a number of enhancements over predecessor satellite communications systems such as high capacity packet switched and circuit switched services in space, and dynamic coding, modulation, and resource allocation for adapting to changing link conditions. However, to realize these potential benefits, we must be able to integrate the future satellite network seamlessly with the existing communication networks such as ADNS and WINT. The satellite links in the ADNS and WINT network are tradition-

ally circuit based and have a relatively simple bent-pipe structure. The future SATCOM system, on the other hand, not only adds another satellite link but also offers packet switched service onboard the satellite which significantly enhances its transmission capacity and link utilization, and reduces its transmission delay. These greater capabilities also render more complexity in integrating the emerging satellite system with existing protected communication networks.

The Navy shipboard communications systems will include Advanced Extremely High Frequency (AEHF), Wideband Gapfiller Satellite (WGS), Mobile User Objective System (MUOS), commercial SATCOM and Line-of-Sight (LOS) radios such as JTRS [2]. The ADNS router, or a Customer Edge (CE) router managed by the Navy, will be responsible for determining path selection for outbound ship traffic. This path selection problem is complicated more by the time-varying nature of the satellite link. The future SATCOM system uses Dynamic Bandwidth Resource Allocation (DBRA) to dynamically assign uplink and downlink terminal transmission modes based on current channel conditions, traffic demand and priority levels, and system resource availability. The terminal transmission mode corresponds to its modulation format, coding rate, and burst rate. During clear weather, bandwidth efficient modes can be used to provide higher burst rates and potentially higher data rates. Under poor weather and jamming conditions, power efficient modes may be used, resulting in a lower throughput on the satellite link.

Intelligent decisions have to be made on which path to route the user network traffic when multiple paths (e.g., WGS, LOS) exist to the destination through different transit networks. Ideally, these routing decisions should be made based on current link state information of the available links, including the future SATCOM uplink. In this paper, we explore how to make these routing decisions dynamically to mitigate the potential rate mismatch and

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make more efficient use of available links when integrating the ADNS network with the future SATCOM network.

Ideally, we'd like to use the satellite link when the uplink capacity is large and use other available links when the satellite link is poor. Such scheme will require the router to have the information about the satellite link and be able to reroute traffic based on the information. However, to our best knowledge, no COTS router has the aforementioned capability of routing traffic based on link state information that reflects satellite link quality. To circumvent this difficulty, we propose to use a software router agent implemented in software to automatically reconfigure the CE router's OSPF metric based on the real-time satellite link state information. To see this, we first explain the major components of a future SATCOM terminal. For the scope of this paper, the future SATCOM terminal can be split into the following functional areas: the digital core or XDR+ terminal modem, the terminal command software, and the terminal router, shown in Fig.1. The XDR+ modem performs all requisite signaling functions, such as link-layer framing, encoding, interleaving, and modulation, required for transmission and reception of over IF. The terminal command software configures both the digital hardware core and terminal router, and also performs terminal command functions such as generating and processing TCRC messaging. The terminal router provides the necessary IPv6 functionality needed by a terminal, and integrates with the modem to accommodate the varying data rates resulting from DBRA uplink resource assignments [1]. The router agent that we propose communicates directly with terminal software agent to poll DBRA assignment information. From the DBRA assignment, the router agent can infer the link state of the satellite link and set appropriate OSPF cost on related interfaces of the CE router. One of the key advantages of this approach is that the router agent does not directly measure the satellite link quality but merely leverages information that is already available in the SATCOM terminal in the form of a DBRA assignment.

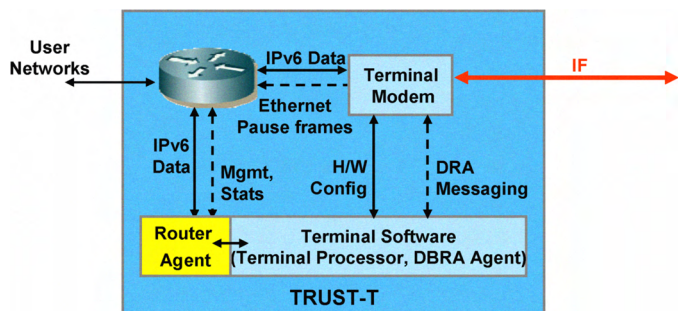


Figure 1. Packet connectivity within Lincoln Laboratory implementation of a SATCOM Terminal Suite.

In this paper, we consider the scenario of two navy ships communicating with each with two available paths: a path through satellite and a LOS path. On the satellite path, packets are routed through CE router, which is managed by the Navy, the terminal router, and payload router. On the downlink, packets are routed from payload router, through terminal router, and the CE router on the destination ship. Currently, the future SATCOM network baseline for routing services calls for both inter-domain and intra-domain routing protocols to be used to interface to Naval ADNS networking platforms. However, the use of BGP alone at the future SATCOM-ADNS interface will limit the traffic that may be routed via the future SATCOM network when other ADNS intra-domain links are active. Routes learned through interior gateway protocols (IGPs) to other ADNS platforms or shore sites via an IGP such as OSPF will be preferred to the type-5 external Link State Advertisement (LSA) redistributed into the ADNS routing domain by the BGP process on the Navy future SATCOM terminal router. As such, an OSPF extension to BGP/ MultiProtocol Label Switching (MPLS) based VPN solution is being considered to permit concurrent use of both satellite and non-satellite paths for ADNS off ship communication [5]. Unfortunately, an IPv6 implementation of this functionality is not currently supported by COTS routers. Instead, we will establish an all IPv6 GRE tunnel between the two CE routers through the satellite network. We also set up a Line-of-Sight link between the two CE routers. Hence, when applications in two ships want to communicate with each other, there are two possible paths for the packets to traverse.

Our experimental results indicate that our router agent is able to make intelligent decisions based on DBRA information and change the OSPF cost on the CE router in a timely fashion. The ability to reroute the traffic based on DBRA information greatly enhances the efficiency of link utilization, which results in improved service quality. The functionalities of the router agent should not be restricted to the ones shown in this paper. Here, we try to illustrate the concept of having the router agent gathering information such as link state and making a better routing decision. Given multiple transmission links existing between a pair of communicating Navy nodes, a more sophisticated router agent can gather all of relevant information about these links and make routing decisions based on different algorithms.

The rest of the paper is organized as follows: in Section II, we describe the detailed ADNS and the future SATCOM testbed and the experimental setup. In Section III, the result of the experiment will be presented. Section IV concludes the paper.

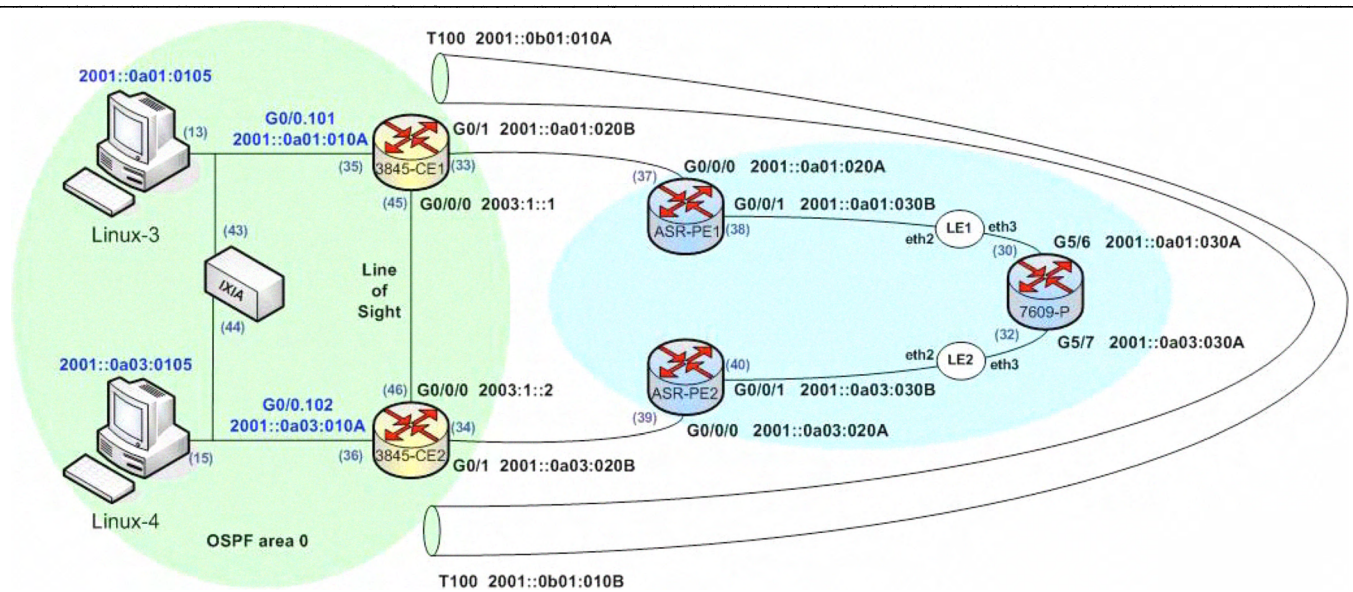


Figure 2. ADNS and future SATCOM testbed setup.

II. EXPERIMENT SETUP

In this section, we describe the testbed that we constructed to study the interaction between the ADNS network and the future satellite network. The experiment topology is illustrated in Fig. 2. In this experiment, we study a typical navy communication scenario where two ships wish to communicate with each other. They have connectivity through the satellite network, and a Line-of-Sight (LOS) link between the two ships also allows them to communicate directly.

In the experiment, ADNS routers operate as Customer Edge (CE) routers and are emulated using the Cisco 3845. The SATCOM terminal routers are Provider Edge (PE) routers and are emulated using Cisco ASR 1004 routers. The payload router is emulated using a Cisco 7609. Two Linux workstations and an Ixia traffic analyzer are also included in the testbed to generate user traffic and applications. We group all of the Navy’s applications and routers into one autonomous system, which includes Linux-3, Linux-4, CE1 and CE2. The terminal routers (PE1, PE2) and the payload router are grouped into another autonomous system.

To emulate the satellite link between the terminal router and the payload router, we insert a link emulator and a pause frame generator between the terminal and payload router. Both the link emulator and the pause frame generator are installed on a Dell PowerEdge 2950 server. Each link emulator delays the packet transmission on the link by

1 second, resulting in a combined delay of 2 seconds when traversing both the uplink and downlink. The pause frame generator is a piece of software that generates pause frames and sends them to the terminal router’s port which connects the Dell server. We know that the rate at which the terminal router forwards data traffic to the modem must match the available RF uplink rate assigned to the terminal by DBRA. One way to achieve this flow control is to employ Ethernet pause frames. When the offered uplink load of user data traffic is greater than the uplink RF rate, the XDR+ modem transmits an Ethernet pause frame to the terminal router. Upon reception of the pause frame, the router ceases transmission of packets out of the port facing the terminal modem. Having the ability to generate pause frames of arbitrary pattern, the pause frame generator allows us to imitate any real DBRA assignment in our testbed. One reason we selected the ASR 1004 as the terminal router is due to its performance with pause frames. Experiments show (not included here) that the ASR 1004’s bandwidth sharing and priority properties are preserved when pause frames are sent to the router.

Since ADNS requires range extension service from the future SATCOM network, user network OSPF routes need to be propagated between the multiple user terminals via the SATCOM domain. This includes establishing a tunnel for a Virtual Private Network (VPN) within an all IPv6 environment and allowing OSPF packets to be sent through the tunnel. To establish a VPN, the often used tunneling methods are Multiprotocol Label Switching

(MPLS) and Generic Route Encapsulation (GRE). As was stated earlier, there does not currently exist a native IPv6 MPLS capability in COTS routers. That leaves GRE as the only tunneling option. In this experiment, for OSPF packets to pass from CE1 to CE2 through the satellite link, we establish an IPv6 GRE tunnel using the satellite links.

The Ixia traffic analyzer generates traffic streams destined to another port on the Ixia. The packet sizes are uniformly distributed between 100 bytes and 1518 bytes. Three classes of traffic are generated: 120Mbps of BE traffic, 80 Mbps of AF traffic and 40 Mbps of EF traffic. The actual measured arrival rates are 117.1 Mbps, 78.1 Mbps, and 39.0 Mbps for BE, AF, and EF traffic respectively; the difference in rates being a result of the Ethernet inter-packet gap and preamble.

In the ADNS router CE1, traffic streams marked with different DSCP values are placed in separate queues. A common way of allocating resources amongst different queues is to assign a percentage of the egress bandwidth to each of the queues. This is typically achieved via a weighted-fair-share type of scheduling algorithm. The queueing policy on the ADNS CE router, i.e. router CE1 in Fig. 2, is configured as the follows. EF traffic is mapped to the high priority queue and this queue is always serviced first. Of any remaining bandwidth, 80% will be allocated to the AF traffic queue and 20% will be allocated to BE traffic queue. As the total egress data rate is varied using pause frames, the pre-defined queueing policy should ideally remain effective. For example, after the EF queue is serviced first, if the AF queue is assigned 80% of the remaining bandwidth *before* pause frames are applied, this queue should also be assigned 80% of the remaining bandwidth *after* pause frames are applied.

To emulate the link capacity variation due to DBRA, the pause frame generator generates two different pause frame patterns that reduce the PE1's egress rate to Rate1 = 200 Mbps and Rate2 = 100 Mbps. To reduce the PE1's egress rate to 200 Mbps, pause frames with pause duration of 786 μ sec and a rate of 1014 pauses per second are sent. Similarly, to reduce the PE1's egress rate to 100 Mbps, pause frames with pause duration of 896 μ sec and a rate of 911 pauses per second are sent.

The router agent proposed in this paper obtains the DBRA uplink assignment information from the modem. Based on the obtained DBRA uplink assignment, (i.e., the uplink link quality), the agent will then make intelligent decision on whether to reroute the traffic. If rerouting is deemed beneficial, router commands will be sent to reconfigure the ADNS router, for example, changing the OSPF cost metrics. Potentially, the router agent could be a Navy controlled device that polls information on all available links, makes intelligent decisions based on some algorithm, and

sends out commands to configure the ADNS router appropriately.

III. EXPERIMENT RESULTS

The objective of this experiment is to study the use of the router software agent to intelligently route traffic based on the link state of the satellite link. Specifically, given three different class of traffic and two paths between the source and destination nodes, we manipulate the OSPF cost metric to balance the traffic among the two links based on their link state information. The use of policy based routing in load balancing is also explored. To see the impact of utilizing satellite link state information, we measure the traffic throughput on each of the two links for four different configuration scenarios:

- Configuration 1: Only OSPF is used to route the traffic on CE1; link state information of the satellite link is *not* used in making routing decisions; there is no policy based routing.
- Configuration 2: OSPF and policy based routing are configured on CE1; link state information of the satellite link is *not* used in making routing decisions.
- Configuration 3: OSPF is configured on CE1; link state information of the satellite link is used in making routing decisions; there is no policy based routing.
- Configuration 4: OSPF and policy based routing are configured on CE1; link state information of the satellite link is used in making routing decisions.

In this experiment, OSPF cost is configured on all links in an AS including the tunnel link. It can use the default setting or be manually configured. However, once it is set, it will remain constant regardless the link condition.

A: Configuration 1

In this configuration, link state or quality information of the satellite link is *not* used in making routing decisions, and there is no policy based routing. This first configuration serves as a baseline for comparison purpose. The OSPF cost metrics on the two interfaces connected to the satellite link and the line-of-sight (LOS) link are configured according the following three scenarios:

- Satellite link is the preferred link.
- Satellite link and LOS link have the same OSPF cost.
- LOS link is the preferred link.

The results of the experiment are presented in the following Tables 1-4. In Table 1, under Rate 2, the BE traffic has a throughput of 0.78 Mbps instead of the expected throughput of 12.6 Mbps (20% of the remaining bandwidth). This discrepancy is due to the ASR1004's bandwidth sharing implementation.

Satellite Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	36.8	36.7	36.7
	Latency (sec)	2.00077	2.00125	2.00377
AF	Throughput (Mbps)	73.6	73.6	62.5
	Latency (sec)	2.00078	2.00335	2.43342
BE	Throughput (Mbps)	110.5	91.2	0.78
	Latency (sec)	2.00078	2.08094	10.9964

Table 1: Satellite link throughput when the Satellite link is the preferred link.

Satellite Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0
AF	Throughput (Mbps)	75.8	75.8	75.8
	Latency (sec)	1.96904	1.96904	1.97234
BE	Throughput (Mbps)	113.7	113.7	30.1
	Latency (sec)	1.96926	1.96926	2.27735

Table 2: Satellite link throughput when the Satellite link and the LOS link have the same OSPF cost.

LOS Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	39	39	39
	Latency (sec)	0.00016	0.00016	0.00016
AF	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0
BE	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0

Table 3: LOS link throughput when the Satellite link and the LOS link have the same OSPF cost.

LOS Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	39	39	39
	Latency (sec)	0.00017	0.00017	0.00017
AF	Throughput (Mbps)	78.1	78.1	78.1
	Latency (sec)	0.00017	0.00017	0.00017
BE	Throughput (Mbps)	117.1	117.1	117.1
	Latency (sec)	0.00017	0.00017	0.00017

Table 4: LOS link throughput when the LOS link is the preferred link.

By setting the satellite link to be the preferred link, we see from Table 1 that traffic is successfully transmitted when there is no pause frames. When the egress rate of the router was reduced to 200 Mbps and 100 Mbps, the throughput of BE traffic was reduced to 91.2 Mbps and 0.78 Mbps. The throughput of EF traffic is unchanged due to its high priority. When the satellite link and the LOS have the same OSPF cost, router CE1 load-balances traffic based on the traffic's source and destination address. In our case, AF and BE traffic are still use the satellite link for their transmission, and EF traffic uses the LOS link for its transmission. Only BE traffic is dropped when the router's satellite facing interface was reduced to Rate 2. When the LOS link was set to be the preferred link, all traffic is transmitted with no packet drop.

B: Configuration 2

In this configuration, the OSPF cost metrics and policy based routing are used together to achieve the desired load balancing objective. Here, the OSPF cost metrics are configured such that the satellite link is the preferred link, but policy based routing is used to force EF traffic over the LOS link. The throughput result is shown in Tables 5-6.

Satellite Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0
AF	Throughput (Mbps)	73.6	73.6	73.6
	Latency (sec)	2.00075	2.00135	2.00215
BE	Throughput (Mbps)	110.5	110.5	26.6
	Latency (sec)	2.00075	2.00135	2.28756

Table 5: Satellite link throughput when the satellite link is the preferred link. EF traffic uses LOS link based on policy.

The results show that while policy routing and OSPF cost metrics can be used together to achieve load-balancing, this method does not react to changes in link quality.

LOS Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	39	39	39
	Latency (sec)	0.00017	0.00017	0.00017
AF	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0
BE	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0

Table 6: LOS link throughput when the satellite link is the preferred link and EF traffic uses LOS link based on policy.

C: Configuration 3

Satellite Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	36.8	0	0
	Latency (sec)	2.00077	0	0
AF	Throughput (Mbps)	73.6	75.8	75.8
	Latency (sec)	2.00078	1.96987	1.97034
BE	Throughput (Mbps)	110.5	113.7	30.1
	Latency (sec)	2.00078	1.96964	2.28326

Table 7: Satellite link throughput when the satellite link and the LOS link have the same OSPF cost.

LOS Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	0	39	39
	Latency (sec)	0	0.00017	0.00017
AF	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0
BE	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0

Table 8: LOS link throughput when the satellite link and the LOS link have the same OSPF cost.

In this configuration, link state information of the satellite link is used in making routing decisions, and there is no policy based routing. Once a link state change is detected (i.e., reduced satellite link bandwidth), the router agent achieves load balancing by changing OSPF link costs. The results of the experiment are presented in the Tables 7-8. From these two tables, we see that when the satellite link bandwidth is reduced to Rate 1, 200 Mbps, the router agent detects the reduction and load balances the two links by setting the OSPF metrics of the two links to the same weight. At this point the load-balancing mechanism of CE1 executes and decides to forward EF traffic over the LOS link, and that AF and BE traffic will still traverse the satellite links. Once the satellite bandwidth is reduced to Rate 2, 100 Mbps, even more BE traffic is dropped. Hence, the nature of the router's load-balancing algorithm results in packet loss even though capacity is still available on the LOS link.

Note that in these experiments it is observed that once the router agent sends commands to CE1 setting link costs to be equal, it takes approximately 15 seconds for CE1 to update its route tables. This is tolerable for us since we do not envision the router to reroute traffic on the scale of seconds.

D: Configuration 4

In the previous configuration, most of the BE traffic is dropped when the satellite link rates are reduced. Ideally, EF traffic and BE traffic would be load balanced to use the LOS link after a reduction in rate on the satellite link is detected, resulting in no packet drop. In this configuration we investigate the use of policy-based routing in conjunction with OSPF to load balance the traffic, so as to avoid packet drop. Specifically, using policy-based routing, we assign EF traffic to the LOS link and AF traffic to the satellite link. The satellite link is also the preferred link for the BE traffic before the satellite link degraded. As the satellite link rate is reduced, the software agent changes router's OSPF metrics and causes the BE traffic to be re-routed through the LOS link. The results of this experiment are shown in Tables 9-10. The experimental results confirm the use of a router agent as a viable option for re-routing traffic based on link state information. Note that after the OSPF cost change, if a stream is re-routed, its transmission is momentarily interrupted for a few seconds before it is resumed on the new route.

Satellite Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0
AF	Throughput (Mbps)	73.6	73.6	73.6
	Latency (sec)	2.00082	2.00128	2.00128
BE	Throughput (Mbps)	110.5	0	0
	Latency (sec)	2.00083	0	0

Table 9: Satellite link throughput when software agent is used to reroute the BE traffic.

LOS Link		No pause	Rate 1	Rate 2
EF	Throughput (Mbps)	39	39	39
	Latency (sec)	0.00016	0.00016	0.00016
AF	Throughput (Mbps)	0	0	0
	Latency (sec)	0	0	0
BE	Throughput (Mbps)	0	117.1	117.1
	Latency (sec)	0	0.00016	0.00016

Table 10: LOS link throughput when software agent is used to reroute the BE traffic.

We now address the complexity in implementing a router agent. The router agent consists of a C/C++ program and an Expect script. The C/C++ program performs the link monitoring operation and reconfigures the OSPF cost of CE-PE link if needed. The Expect script sends the CLI commands to the CE router on behalf of the C/C++ program and forwards the response and/or status information back to the C/C++ program. With the current implementation, there are approximately 1200 lines of code in the C/C++ program and around 800 lines of code in the Expect script. A significant portion of this code can be reused if more functions were to be added. Note also that the current implementation does not include a complex algorithm to calculate the OSPF cost of CE-PE link according to the link quality analysis of satellite link. The OSPF cost is determined primarily based on the satellite link bandwidth only. Other factors, such as link utilization, delay, could be included in the calculation of OSPF cost in the future.

To implement the policy-based routing, the following steps are needed. First, we define an access list for each traffic

class being considered. Next, we create a route map. This map describes the designated egress interface for each list defined in the first step. Finally, we enable the route map on the interfaces where the policy should be applied. To configure the policy-based routing, the total number of CLI commands on a Cisco router depends on the complexity of the access list definition and route map. For example, ~20 CLI commands are used to set up the policy-based routing for EF and AF traffics in this experiment.

Not included in this work is any investigation into the area of network route stability. Even if the router agent can poll the quality of links very frequently, it is likely the decision algorithm may want to include some hysteresis to ensure route stability in the network and minimize the potential of extreme route churn.

IV. CONCLUSION

In this paper, we assess the impact of a variable rate satellite link on the existing communication network. We propose the use of a router agent to dynamically reroute traffic based on real time uplink channel assignments. A series of experiments were conducted to validate the proposed method and showed the proposed solution can mitigate potential rate mismatches and make more efficient use of available links.

Another measurement-based technique that performs dynamic route selection is Cisco's Optimized Edge Routing (OER). It allows a network administrator to monitor IP traffic flows and then define policies and rules based on traffic class performance, link load distribution, link bandwidth monetary cost, and traffic type [2]. In our future studies, we may investigate whether it is feasible to use OER as an alternate for load balancing.

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REFERENCES

- [1] J. Wysocarski, A. Narula-Tam, M. Wang, and R. Kingsbury, "Integrating COTS Routers Into Terminals for Future Protected SATCOM Systems With Dynamic Resource Allocation," *IEEE MILCOM 2007*, Oct 2007.
- [2] J. N. Ptasinski and Y. Congtang, "The Automated Digital Network System (ADNS) Interface to Transformational Satellite Communications System (TSAT)," *IEEE MILCOM 2007*, Orlando, FL.