A Multi-path TCP Solution for Software-Defined Military Heterogeneous Network

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Abstract—Naval Battlefield Network communications rely on various wireless network technologies for data delivery between different entities such as ships and shore nodes. A critical problem in current military wireless networks is that a loss of network connectivity due to wireless link outage or entity mobility takes relatively long time to recover. In this paper, we propose an alternative solution by applying Multi-path TCP and Software-Defined Networking on military wireless network to maximize the total throughput and minimize the traffic delay and jitter for the communication between ships and shore nodes. According to the Mininet-WiFi emulation experiment results, compared to current single-path TCP communication, our proposed approach provides almost no-cost network handover, more reliable network connectivity and higher end-to-end throughput. In addition, our designed SDN centralized controller is able to balance the traffic flows dynamically to effectively eliminate link congestion and achieve higher bandwidth utilization.

Index Terms—Software-Defined Networking, Multi-path TCP, Wireless, Heterogeneous Network

I. EXTENDED ABSTRACT

The Naval Battlefield Network (NBN) is the entirety of naval assets that are interconnected via one or more communication links. Examples of naval communication assets are sea surface vessels, aircraft, land or shore based fixed sites and ground expeditionary forces. Communication among them is enabled by governmental and commercial satellite communication systems (SATCOM). For example, navy ship is equipped with one or more SATCOM terminals and a router arbitrates traffic from shipboard local area networks (LAN) to these terminals, which is then forwarded to the SATCOM network through a dedicated uplink [1]. As Fig. 1 shows, the ground combat element (GCE), composed primarily of infantry units, always need to communicate with their headquarters unit, which provides command and control. In the conventional architecture, GCE uses single-path communication via SATCOM. However, a significant problem with single-path communication is that even momentary link outages cause a loss of network connectivity that may take more than two minutes to recover. The problem is even more severe when there are faster links to reach the headquarters unit, e.g. via Unmanned aerial vehicle (UAV). Switching between different available links interrupts the communication and manual intervention has to be given by soldiers. Such communication interruption and manual intervention can lead to serious consequences in the battlefield. On the other hand, GCE would always prefer the faster available link since the communication with headquarters unit is time sensitive. Therefore, a faster UAV link can become congested due to traffic overload while the capacity of other SATCOM links are underutilized. To overcome the problems brought by single-path TCP (SPTCP), our solution uses Multi-Path TCP (MPTCP) instead of single-path TCP to maintain network reliability and pursue higher end-to-end throughput. Meanwhile, Software-Defined Networking (SDN) is applied as well to enable real-time traffic engineering, e.g. balancing the traffic over multiple TCP connections dynamically.

A. Solution Design

We propose the solution that combines MPTCP and SDN to optimize the communication in SATCOM and mobile UAV heterogeneous network. The network consists of ships (as host nodes), multiple SATCOM systems and UAVs (as data service providers), GCEs (as data customers), one SDN switch per ship for managing the traffic and one centralized SDN controller serving as the SATCOM and UAV bandwidth broker. GCEs are equipped with multiple network interfaces and enable MPTCP so that they can utilize multiple links to communicate with ships. The SDN controller collects statistics from the network, such as link capacities, topology changes, and then deploys and updates the traffic flow distribution against the demand of GCEs according to the result generated from an improved Flow Deviation Method (FDM) algorithm [2]. The improved FDM algorithm supports dynamic traffic flow allocation and minimizes the impact on the current network due to the traffic flow re-allocation.

1) Multi-path TCP: Multi-path TCP [3] is an extension and enhancement to conventional single-path TCP by leveraging the availability of multiple data paths on multiple interfaces...
between a pair of hosts to increase the reliability at end-to-end communication. It combines application sub-flows into one single logical connection to attain higher throughput. MPTCP runs between the applications and TCP sub-flows and the handover is fully transparent to higher layers. It reconstitutes out-of-order packets from different sub-flows and performs coupled congestion control among them. We deploy MPTCP in our scenario to achieve smoother reaction to network changes due to the emerging of bursty faster link via UAVs. Once the GCE approaches the UAV or the UAV flies into the range of GCE, new link can be established instantly and joined with the existing SATCOM link. The key benefits are: a) immediately utilize the bursty faster link with almost 0-cost; b) no communication interruption at all.

2) **Software-Defined Networking**

Software-Defined Networking is an emerging concept that isolates the network control plane from data forwarding plane. This isolation allows the centralization of network logic and topology information in the network control plane, hence turning commodity hardware routers and switches into simple packet forwarding devices [4]. Introducing SDN to SATCOM system is also feasible since [5] has already successfully divided SATCOM channels into control and data plane to fit SDN architecture. In our scenario, an important problem introduced by MPTCP is network may run into congestion when the bursty faster UAV link has limited bandwidth, which is unfortunately less than the total demand of GCEs. The most common traffic scheduler of MPTCP is Lowest Round Trip Time First (LowRTT), which chooses the sub-flow with lowest RTT to be the primary path and forces MPTCP traffic to preempt the bandwidth of that path greedily. Therefore, we leverage SDN with our own designed controller to help MPTCP distribute the flow less greedy to avoid congestion and gain load balancing.

**B. Experiment and Evaluation**

Mininet [6] provides a virtual network environment that consists of hosts, SDN switches, and SDN controller. Mininet-WiFi [7] is an extension of Mininet by adding virtualized WiFi station and access point (AP) based on the standard Linux wireless drivers and the 802.11 hwsim wireless simulation driver. We conduct our experiments on Mininet-WiFi to emulate our scenario involving MPTCP, SDN, and SATCOM/UAV heterogeneous network. In particular, each host is a virtual representation of the physical machine. The hosts enable MPTCP protocol to access available bandwidth from multiple SATCOMs and UAVs. For SDN switches and the controller, we use Open vSwitch, and our own designed controller respectively. We simplify the scenario topology properly to one host node as ship, one UAV as wireless AP, one switch as SATCOM system and three station nodes as GCEs. Also we emulate the SATCOM link by ethernet and the UAV link by normal 802.11g wireless network. The backhaul network from SATCOM to host is set to 50Mbps capacity and 250ms delay and from UAV to host is set to 1Mbps capacity and 10ms delay respectively. Each GCE node has 1Mbps demand. At last, we randomly choose two positions outside/inside the range of the UAV as the starting/ending point of the mobility trace for each GCE. We use D-ITG [8] to generate 1Mbps traffic for GCEs. The total emulation time is 150s and the GCEs step into the range of UAV exactly at 65s. The results are shown in Fig. 2, 3 and we can see the advantages clearly: a) the overall throughput of MPTCP increases up to 50% especially when the bursty faster UAV link is available; b) communication never gets interrupted while the SPTCP has around 5 seconds link failure gap in order to switch the link from SATCOM to UAV; c) UAV link still has available capacity while the SPTCP has already been saturated totally; d) average packet delay is less than half of the delay in using SPTCP.

![Fig. 2. Average throughput (Left) and packet delay (Right) over three GCEs for MPTCP+FDM and SPTCP experiments.](image)

![Fig. 3. Throughput over time of UAV and SATCOM communications for MPTCP+FDM and SPTCP experiments. Red curve is the throughput of UAV communication and blue curve is SATCOM’s. Yellow curve is the total throughput for all GCEs for MPTCP+FDM experiment.](image)

**REFERENCES**


