Study of Data Transfer Nodes Infrastructure in Enabling Big Data Movement between Research and Cloud Storage Networks

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***Abstract* -Data research projects generate huge amounts of data, which are usually stored in cloud networks for processing and storage. Transferring large amounts of data between multiple research sites, often within protected scientific DMZs (Demilitarized Zone) and cloud storage nodes, requires high-speed network connections.**

To ensure efficient data transfer and processing, parallel data streams are used between multiple research sites, with dedicated cloud infrastructure for processing and storage of a particular experiment. Since multiple nodes or sites are involved in data transfer, DTNs (Data Transfer Nodes) are used to solve the problems of fast data flow and performance between nodes that are not related to network throughput. DTNs include software transfer tools and high-end hardware components that are tasked with preparing data for transfer.

Several research groups are working to establish multiple DTN instances as part of a large-scale scientific data network. This paper provides a brief overview of the current state of the art in the use of DTN infrastructure and the challenges associated with preparing data for transfer.

***Keywords* - DTN (Data Transfer Node), Science DMZ (Demilitarized Zone), big data transfer, orchestration of data streams**

I. Introduction

A network transfer node is a point in a network where data, signals, or messages are transferred from one network to another. It can also be a device or system that serves as a connection point between two or more networks, enabling the transfer of data between them. Network transfer nodes can be used to connect different types of networks, such as local area networks (LANs), wide area networks (WANs), and the Internet. They can also be used to interconnect different types of devices such as computers, servers, storage, routers, and switches to enable communication and data transfer between them.

There are several factors that can limit the full network throughput on a network. Some common limitations are [1]:

- Bandwidth: The amount of data that can be transmitted over a network is limited by the available bandwidth. If the network is congested or bandwidth is limited, this can affect throughput.
- Latency: Latency or delay on a network can also affect throughput. A delay in the transmission of data can reduce the overall throughput of the network.
- Protocol overhead: Protocols such as TCP/IP are used to transmit data across a network. However, these protocols have overhead, which means that some of the available bandwidth is used for protocol-related tasks and is not available for data transmission. This can limit the throughput of the network. The delay between the conformance packet and the "ready to send next batch" or retransmission signal can also play an important role in controlling protocol overhead.
- Interference: Interference from other devices or sources, such as wireless interference or physical obstacles, can also affect the throughput of a network.
- Device capabilities: The capabilities of devices connected to the network can also limit throughput. For example, if a device has a slower processor or limited memory, it may not be able to process or transmit data as quickly as a more powerful device.

Data Transfer Nodes (DTN) [2] are defined as network nodes that are used to transmit data from one site to another and are used exclusively for data transmission. DTNs should also match the capabilities of the site and WAN infrastructure where the node is installed. They are also commonly used to transfer data over long distances or when data needs to be transferred between two networks that are not directly connected or immediately accessible. Some examples of where DTN can be used [3]:

- Satellite communications: DTN can be used to transmit data between ground stations and satellites or between satellites in different orbits.
- Space exploration: DTN can be used to transmit data from spacecraft to ground stations or between spacecraft in different parts of the solar system or beyond.
- Emergency or disaster relief: DTN can be used to transmit data in situations where conventional communications networks are unavailable or unreliable, such as after a natural disaster or during a military conflict.

- Remote or isolated locations: DTN can be used for data transmission in areas where there is no direct connection to the Internet or other communication networks.
- When a parallel data stream to one or more sites would be required.

DTNs can be used to transmit a wide range of data types, including text, images, video, audio, or raw data. They are often used in environments where data transmission presents problems, such as low bandwidth, high latency, or broken connections.

DTNs can also be used to transfer data between research centers and cloud storage. In this scenario, the DTN acts as a bridge link between the research center and the cloud, allowing researchers to transfer large amounts of data to and from the cloud without having to use the Internet or other traditional communication networks. This can be useful in cases where the research center does not have a high-speed Internet connection, the data to be transferred is sensitive and must be kept secure, or the destination of the data cloud is unknown (some examples: Put the data on a lower cost cloud storage or put the data on the first available HPC with the required processing parameters for processing).

Using DTN to transfer data between research centers and cloud services can allow researchers to take advantage of the large storage capacity and computational power of the cloud while still being able to work with the data locally at the research center. It can also help improve the speed and efficiency of data transfer, as DTN is designed to handle large amounts of data and can operate over long distances and in challenging environments.

II. DTN NODE DEFINITION AND USAGE

Data Transfer Nodes (DTN) are typically made up of a network of devices that are used to transfer data from one location to another. The specific components of a DTN infrastructure can vary depending on the specific requirements of the system, but some common components include:

- Nodes: DTN nodes are actual hardware devices that are used to transfer data within the DTN network. They can be located at the source and destination of the data transfer, as well as at intermediate locations along the way. DTN nodes can be standalone devices, or they can be integrated into other systems, such as routers or servers.
- Links: DTN links are the communication channels that connect DTN nodes and allow them to transfer data. Links can be physical, such as a cable or fiber optic connection, or they can be wireless, such as a radio or satellite link. In some cases, a DTN link may consist of multiple communication channels that are used in parallel to transfer data.
- Protocols: DTN relies on specialized protocols to transfer data between nodes and ensure that the data is delivered reliably. These protocols can include routing protocols, which determine the best path for the data to take through the DTN network, and error correction protocols, which are used to ensure the integrity of the data. Other protocols, such as flow control and congestion control, can be used to manage the flow of data through the DTN network and prevent the network from becoming overloaded.
- Management: DTN systems often include a management component, which is responsible for configuring and monitoring the DTN nodes and links, and for ensuring that the DTN network is operating efficiently. This can include tasks such as traffic management, load balancing and fault detection and recovery. The management component can be implemented as a standalone system, or it can be integrated into other components of the DTN infrastructure.
- Storage: DTN systems may include storage devices, such as hard drives or flash drives, to store data temporarily as it is being transferred. This can be useful in cases where the DTN network is experiencing intermittent connectivity or where the data transfer rate is slower than the rate at which the data is being generated.
- Security: DTN systems may include security measures, such as encryption and authentication, to protect the data being transferred from unauthorized access or tampering.
- User interface: Some DTN systems may include a user interface, such as a graphical user interface or command-line interface, to allow users to interact with the system and manage the data transfer process.

In addition to these components, DTN systems can also include other hardware and software elements, such as dedicated fast storage devices, security boxes, and user interfaces.

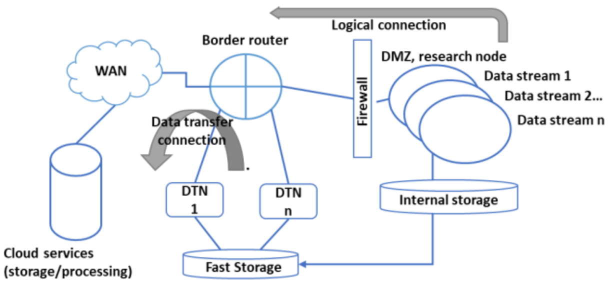

Figure 1. Simplified DTN architecture

The logical connection and real data transfer connection can take different paths within the network, especially in Science DMZ environment as shown in figure 1.

III. Related work

Currently there are multiple research projects within research academic network regarding implementation of DTN in parallel with study of science workflow regarding machine data generation and AI processing of the data in research environments. ESnet (Energy sciences network) has published "Deployment strategy" [4] and know-how documents for starting up DTN implementation, hardware selection and hardware tuning. Recently Paneuropean research network Geant [5] has published findings and testing of DTN deployment of different transfer tools.

Regarding security of inplementation the research paper in 2019 by Jorge Crichigno and others [6] has published a bottom-up approach, from the physical cyberinfrastructure to the application layer and security aspects of DTN in Science DMZ (Demilitarized Zone). The research concluded that DTN can mitigate the deliveries of malicious payloads and also disscussed the advantages and disadvantages of security appliances and techniques, such as ACL (Access Control Lists), IPS (Intrusion Protection System) , IDS (Intrusion Detection System), and related best practices to secure Science DMZs while avoiding performance degradation.

Recently more research was given for maintaining high-capacity, data-intensive network flows in a medical context [7]. Medical research centers have resulted in high-rise of biomedical big data that has to be shared between multiple sites (National Library of Medicine, the National Cancer Institute, European Bioinformatics Institute). The authors describe the ability to store and compute data by a combination of local, national, and industry resources that exchange large data sets using the possibility of DTN.

The paper from Wontaek Hong and others [8] discuss how to enhance the data transfer utilizing DTN between Cloud Service Providers. The paper proposed procedure for transferring VM images to a destination controller that includes local/remote copy processes and a DTN-to-DTN transfer process. The procedure improved throughput by 22%.

IV. Challenges of DTN implementation

Implementing and maintaining a DTN network can be expensive, especially if it involves the deployment of specialized hardware and software, or the use of expensive communication channels, such as satellite links [9]. One of the potential solutions to this challenge is to use a hybrid approach that combines DTN with other technologies, such as the internet, to transfer data. This can help to reduce the cost of the DTN network by leveraging existing infrastructure and taking advantage of lower-cost and shared communication channels. Regarding data storage and processing, a possible cost effective solution is to use a cloud-based DTN service, which can provide access to DTN capabilities without the need to build and maintain a hardware and software infrastructure.

Challenge in using DTN to connect research centers with cloud storage or HPC systems is mostly the limited bandwidth of the DTN network. This can especially be demanding and challenging when transferring enormous amounts of data or when the DTN network is operating over long distances or in remote locations. A potential solution to this challenge is to use high-bandwidth dedicated communication channels, such as fiber optic cables or satellite links, to connect DTN nodes.

Data compression technique to reduce the amount of data can also be a reasonable solution (predictive algorithms, multicast, etc.). Most research centers nowadays are connected via high-speed fiber connection provided by National Research Networks (NREN) which are mutually inter-connected with high network speed.

An important challenge in establishing DTN infrastructure is hardware. These challenges include:

- Reliability: DTN nodes and links must be reliable to ensure that data can be transferred consistently and reliably. This can be especially challenging in environments where DTN nodes and links are subjected to extreme conditions, such as temperature fluctuations, humidity, or physical shock.
- Compatibility: DTN nodes and links must be compatible with each other and with the systems they are connecting to. This can be a challenge when different DTN nodes and links are manufactured by different vendors or when they use different communication protocols or technologies.
- Scalability: DTN networks may need to be scaled up or down as the volume or complexity of the data being transferred changes. This can require the deployment of additional DTN nodes and links, which can be a challenge in terms of cost and complexity.
- Maintenance: DTN nodes and links may require regular maintenance to function properly, including tasks such as firmware updates, hardware repairs, and cleaning. This can be a challenge in situations where DTN nodes and links are located in remote or inaccessible locations.
- Power: DTN nodes and links may require a reliable power source to operate. This can be a challenge in situations where there is no access to grid power or where the DTN network is being used in a mobile or portable setting.

V. Scenarios of DTN orchestration

Data Transfer Nodes (DTN) can use orchestration to manage the flows of data being transferred over the DTN network and to configure bandwidth on demand. Orchestration refers to the process of automating the coordination and management of DTN nodes and links to transfer data efficiently and reliably [10].

In the context of DTN, orchestration can involve tasks such as:

- Routing data: Orchestration can be used to determine the best path for data to travel through the DTN network based on factors such as the location of the source and destination, the volume of data being transferred, and the capabilities of the DTN nodes and links.

- Scheduling transfers: Orchestration can be used to schedule data transfers to optimize the use of DTN resources, such as bandwidth and storage. This can involve tasks such as prioritizing certain transfers over others, or scheduling transfers to take place during periods of low network usage.
- Configuring bandwidth on demand: Orchestration can be used to configure the bandwidth of DTN nodes and links on demand, based on the needs of the data transfer. This can involve tasks such as allocating additional bandwidth to transfers that require it, or releasing bandwidth when it is no longer needed.

Orchestration can be implemented using a variety of technologies, such as software-defined networking (SDN), network function virtualization (NFV), or cloud-based orchestration platforms. These technologies can be used to automate the management and configuration of DTN nodes and links to improve the efficiency and reliability of data transfers over the DTN network.

VI. DTN NODE PERFORMANCE TESTING

Several DTN performance tests were performed on Geant4-3 project using GTS (GÉANT Testbed Service) [11]. GTS enables the research community to create automated platform on which to build virtual networks using dedicated fiber links between sites.

DTN research project was started as research activity to support current and future projects that require large-scale, high-performance transfers via NREN and Geant network. Examples of this include Square Kilometer Array (SKA), Worldwide Large Hadron Collider Computing Grid and AENEAS project.

The testbed scenario included simulated DTN nodes in Geant network located in data centers in London, Amsterdam, Prague, Paris and Hamburg. DTN simulated nodes were directly connected via 10Gbit/s dedicated dark-fiber links. DTN hardware node was evaluated in a configuration role as a virtual machine (VM) or a bare-metal server (BMS).

Maximum fiber length was 2093km on London-Prague link. VMs were generated using OpenStack GTS GUI interfaces and were connected via virtual circuits using Network Service Interface (NSI) across multiple sites on GTS network.

Different hardware was tested primarily Dell PowerEdge R430 (2x20C/40T Intel Xeon E5-2660v3 @ 2,6GHz, 128 Gb ECC DDR4 2133 MHz RAM) and Dell PowerEdge R520 (1x8C/16T Intel Xeon E5-2450 v2 @ 2,5GHz, 32 Gb ECC DDR3 1600 MHz RAM) in VM or BMS configuration.

Several file transfer tools were used in the performance testing:

- iperf - network performance tool used as a reference tool for maximum throughput.
- GridFTP - tool which is an extension to FTP developed for grid computing by Open Grid Forum (widely used tool for data transfers in science projects and supercomputer centers).
- FDT - Fast Data Transfer tool - open-source tool that can use and control multiple TCP data streams via different sockets.
- XtootD - open-source extended ROOT daemon that can utilize load-balancing for multiple data streams in client-server transfers.

In simulation all the hardware components were fine-tuned to give maximum throughput and performance require for high volume data traffic (mtu, packet pacing, I/O Scheduler, data-file system). For the VM the same Docker environment was used with additional tuning on kernel level. The different results were accomplished depending on hardware used or virtualization level.

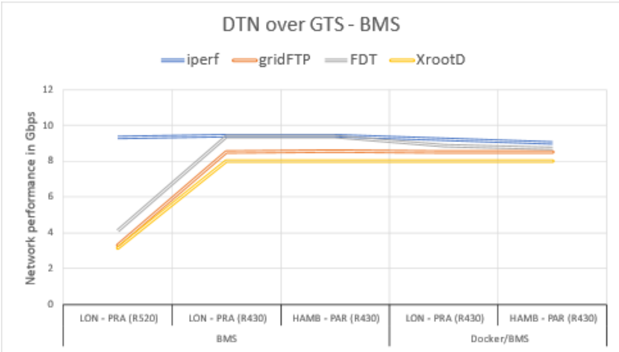

Figure 2 DTN test results of BMS on GTS

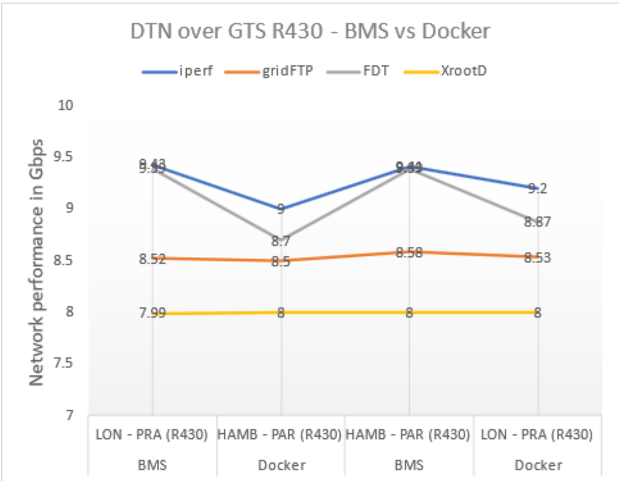

Figure 3 DTN test results over GTS network

Iperf tool was used as a reference point for maximum network throughput. Results of the performance testing of different BMS with same tunning properties, over different fiber channels are shown in figure 2. Results show better performance of FDT tool on all tested scenarios. Figure 3. shows difference in performance of BMS vs. VMs on Docker platform for the same transfer tools and same data file.

XrootD tool give deficient performance in virtual/contained environment since the tool is highly dependent on hardware resources and direct hardware access, while others show similar results and 5% less performance than what was results of iperf reference tool measurement.

VII. Conclusion

Large data transfer is becoming increasingly important as research projects generate vast collections of data that require fast and efficient transfer and processing.

DTN is an innovative solution for the transfer of large amounts of data between research centers and cloud services. The paper has presented several advantages and challenges over traditional data transfer methods in using DTN and constraints for development. Paper also presented performance results of different tools that can be incorporated inside DTN node. It is important that DTN is a separate piece of hardware dedicated only for preparing data transfer and actual data transfer. DTN must be tuned for maximum performance regarding the network interfaces and server hardware components.

DTN provides a versatile and efficient solution for data transfer that is rapidly gaining popularity among researchers and data scientists. With ongoing advancements in technology and research, DTN is set to play an even more crucial role in data transfer and processing in the future.

Future work will include enhancements of performance [12], [13] in regards of reliability of the system, security, increasing the efficiency and speed of data transfer, integration with emerging technologies such as Artificial Intelligence [14], Machine Learning and Big Data Analytics to provide even more powerful data transfer and processing capabilities for research communities.

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