Terabit-speed Packet Marking for Traceability of Scientific Data Across the Globe

Scitags Network Research Exhibition at the IEEE/ACM International Conference on High-Performance Computing, Networking, Storage, and Analysis (SC26), Chicago, Illinois November 15-20, 2026

At the 2026 international supercomputing conference in Chicago an international research consortium demonstrated a new method for marking data packets to identify the specific scientific experiments originating them. Unique about this new method is that it can be sustained at very high speeds (terabits) over global distances, which is needed to keep up with the ever increasing volumes of research measurement data. This marking technique provides operators of the underlying research infrastructure (networks, storage, and compute sites) deep insight into the flow of the scientific data across the globe. This high fidelity insight is important because managing large-scale scientific workflows over international WANs is becoming increasingly complex.

The Need for a New Method

Complexity is increasing because multiple science projects, especially data intensive sciences, share common underlying foundational resources while governed by divergent variables, constraints, technologies, domains, and policies. Hence, precise insight is needed on exactly how measurement data travels from the experimental instrument that generates them to the storage and compute sites where they are analyzed. By marking the packets transporting the measurement data at the experiment, we gain high-fidelity visibility into how individual science domain workflows utilize the international infrastructure's resources. This insight includes visibility into the use of storage, e.g., disk and tape, bandwidth at the end sites, as well use of the terabit network paths it transits across the globe.

At SC26 we demonstrated this marking approach in real life, at real Tbps speeds, in real time. An example of a motivation for this approach is the forthcoming High Luminosity Large Hadron Collider, which will generate ten times the amount of data currently generated by the existing LHC, which generates hundreds of petabytes per year that are streamed to computation sites world-wide. This demonstration showcased the utility of scientific network tags (Scitags), an open-source initiative promoting high fidelity flow visualization for individual streams, production workflow monitoring, and analytics.

Participants

The participating sites include the University of Victoria in Canada, as a proxy for the TRIUMF Tier 1 computation site, Fermi National Accelerator Laboratory (FNAL), a US Tier 1 computation site, European Organization for Nuclear Research (CERN) in Switzerland that hosts the Large Hadron Collider, the StarLight International/National Communications Exchange Facility in Chicago, the NetherLight Global Exchange Point run by SURF in the Netherlands, and the StarLight booth at the SC26 venue. Each sending and receiving site was provisioned with multiple high-performance 400 Gbps Data Transfer Nodes (DTNs), optimized for high performance WAN transport. The University of Victoria has been connected to StarLight by 3*400 Gbps paths on the

NA-REX national testbed. For SC26, two additional 800 Gbps paths (1.6 Tbps) were provisioned over NA REX, using coherent optics from the University of Victoria to Seattle, before transitioning to open line transport over the NA REX network to StarLight in Chicago. The paths to CERN were provisioned with multiple 300 Gbps VLANs, distributed across six 400 Gbps production transatlantic circuits, provided by the Advanced North Atlantic network (ANA), CANARIE, GEANT, Internet2, NEA3R, NORDUnet, SINET, SURF and FABRIC. These VLANs were built using a new multi-domain provisioning system developed by the ANA. These demonstrations provided important measurements preparing for the WLCG Data Challenge in early 2027, for which a significant fraction of storage elements are expected to enable packet marking.

These demonstrations showed how any intermediate network or end-site can easily identify both the owner and the purpose of the traffic, providing standardized and detailed visibility into the nature of HEP traffic running to and from their sites, leading to efficient methods of precise traffic engineering and shaping, providing opportunities for AI integration, and shaping architecture for even more data intensive future science research. These demonstrations employed multiple software tools. Transfers were accomplished using iperf3 to assess the maximum achievable bandwidth. Also, xRootd and dCache were used to demonstrate the viability of packet marking in disk-to-disk transfers and assess the bandwidth achievable in that case. Live production demonstrations were conducted with flow labelling ("fireflies”), in collaboration with US/ATLAS and US/CMS sites. The sites actively participated by exchanging data over production networks. Monitoring dashboards showed the flows sorted by applied scientific activities and reported live results directly at the StarLight booth on the SC26 show floor. These demonstrations also showcased the utility of SENSE (Software-Defined Network for End-to-End Networked Science at the Exascale), an open-source, model-based network orchestration project led by the Energy Science Network (ESnet) as a provisioning method, especially for implementing several complementary paths across multiple international circuits.

The Scitags initiative (www.scitags.org) is an open international collaboration that originated as a WLCG Networking Technical Working group developing practical networking capabilities for HEP research using National Research and Education Networks (NRENs). The consortium staging these SC26 Scitags demonstrations included CERN, University of Victoria, BCnet, CANARIE, Fermi National Acceleratory Laboratory, the Pacific Wave, the Pacific Northwest GigaPoP, StarLight, NetherLight, NA-REX, the International Center for Advanced Internet Research, Northwestern University, the Metropolitan Research and Education Network (MREN), Internet2, ESnet, University of California San Diego, SC26 SCinet WAN, LHCOPN, LHCONE, Indiana University – NEA3R, the Advanced North Atlantic network, the University of Michigan, Ciena, HPE, Internet2, NORDUnet, SURF, FABRIC, SINET, KDDI, and the National Institute of Informatics (NII).