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PerfSONAR: An Importance of Multi-Domain Network Monitoring

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Abstract*: Research community interacts by means of multi-domain networks. Operating policies, set of hardware components, customers, bandwidth configuration varies from network to network. Hard failures like fiber cut, power failures are easy to detect while soft failures which result in packet loss and degrade the throughput are difficult to detect. Present network monitoring tools are subject to single administrative domain. Hence, network cannot be monitored over multiple domains. Performance focused Service Oriented Network monitoring ARchitecture (perfSONAR) is designed and developed by open source community which supports advanced level of network monitoring across multi domain network. In this paper, I have focused on the importance of multi-domain network monitoring and reviewed the work of perfSONAR proposed by various researchers.

***Keywords* : Hard failures, soft failures, perfSONAR.**

I. INTRODUCTION

Lots of tools are available to monitor network metrics like packet loss, delay throughput and many more. Using present tools it is very difficult to detect soft failures which result in degradation of throughput. Further, if the information from different administrative domains is required then the circumstances get much more complex. To overcome on all these problems, the open source community have developed and implemented Performance focused Service Oriented Network monitoring ARchitecture (perfSONAR) [1]. perfSONAR aims to discover end-to-end performance monitoring issues on paths across multi-domain network environment.

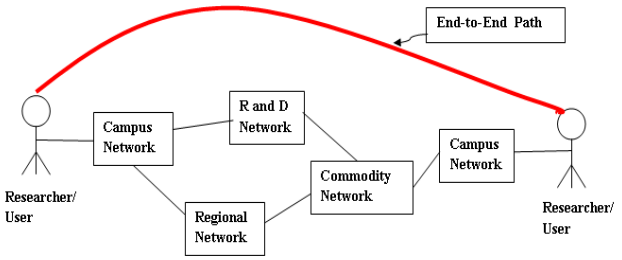

Fig.1. End-to-End path across multi domain environment [1]

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perfSONAR research team partners are GEANT2, RNP, Internet2, and ESnet [1]. Two versions of perfSONAR are: A version by Internet2 (R&D high-speed test bed network in the United States) which is Perl-based and a version by GEANT2 which is Java-based [1][4]. The extended framework of the perfSONAR developed in Perl language, names as perfSONAR-PS. Permanently running services using perfSONAR are DAEMON and ECHO services. These services are responsible for the Measurement Archive (MA) service and current status exchange which controls data saving and retrieval. perfSONAR provides different services to carry out each network measurement metrics. It is flexible, scalable and open for R & D community. In this paper I have focused on the need of perfSONAR and presented the review of perfSONAR framework proposed by various researchers. The paper is organized as follows: Section II is focused on the basics of perfSONAR. In section III, I have presented the state of art of network monitoring across multi-domain network environment using perfSONAR. Section IV presents the summary of literature reviews presented in section III and section V concludes the paper.

II. BASICS OF PERFSONAR

In this section I have described a Service Oriented Architecture (SOA) proposed in [2] which supports multi domain measurement performance metrics. Multi-domain network monitoring framework consists of three layers: The Measurement Points Layer (lowest layer), the Service Layer (middle layer), and the User Interface Layer (top most layer) as shown in figure 2. The Measurement Points Layer is responsible for providing fundamental network information. It consists of different monitoring agents who provide information of various metrics like residual bandwidth, delay, jitter, packet loss, etc. The service layer contains administrative domains which are responsible for efficient resource utilization, approval and confirmation of information and/or users. Graphical tools are the part of the User Interface Layer. Using graphical tools the users interact with the lower layers of the monitoring framework. The Measurement Points Layer is responsible for Measurement Point Services (MPS).

The service layer provides the following services: Measurement Archive Service (MAS), Authentication Service (AS), Resource Protector Service (RPS), Lookup Service (LS) and Transformation Service (TS). MPS activates active measurements or sends query to passive measurement devices and generates measurement data. The MPS can act as a server as well as a client.

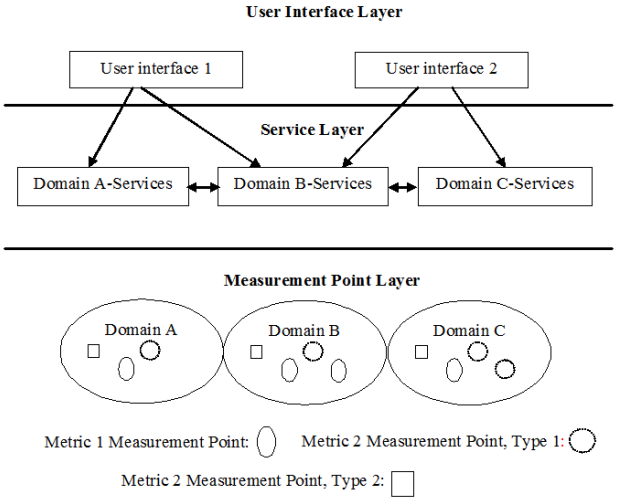

Fig.2.SOA architecture [2]

Table 1: perfSONAR Services

perfSONAR service	Summary
Measurement Point Services	• Generates measurement data • Distributes measurement data to the subscribers • Publishes data results to the clients
Lookup Service (LS)	• Helps clients/users to determine their desired services • Accepts requests for registration and deregistration and service-related information. • Shares directory information with other LSs in case of peer-to-peer networks
Measurement Archive Service (MAS)	• Stores and distributes the measurement data produced by MPS/TS • Can help for detailed analysis by providing past record • Accepts the setup and publication requests • Distributes the measurement data
Authentication Service (AS)	• Protect user privacy using role-based authentication • Provides the authentication and authority services to the clients/users
Transformation Service (TS)	• Performs translation of data, correlation, aggregation, and filtering services • Generate Alarm Notification Service
Topology Service (ToS)	• Provides topological information regarding the network accessible to the framework
Resource Protector Service (RPS)	• Responsible for efficient utilization of resources, specially bandwidth

When MPS acting as a server, it accepts the requests from clients and publishes data results to the clients via the subscriber handles. While MPS acting as a client, it registers itself with LS and distributes measurement data to the subscribers. LS is responsible for registering various services with their capabilities. By querying LS, the clients determine their desired services. When acting as a server, the LS accepts requests for registration, deregistration and service-related information, while LS acting as a client, it registers itself to the other LSs. LS shares directory information with other LSs in case of peer-to-peer networks. The MAS stores and distributes the measurement data produced by MPS/TS. The MAS is also responsible to reduce queries to the MPS and provides past record for detailed analysis. When acting as a server, the MAS accepts the setup and publication requests, while acting as a client, the MAS registers itself with LS and also subscribes itself to the other MAS, MPS or TS and distributes the measurement data. The AS provides the authentication and authority services to the clients. Privacy of user is protected using role-based authentication. While acting as a server, the AS accepts requests of authentication and attributes and while acting as a client, it registers itself with LS. The TS performs translation (e.g. high resolution data to low resolution data), correlation (e.g. TS may read from multiple data publishers), aggregation, and filtering services. Alarm Notification Service is a special type of TS. When acting as a server it accepts publication requests while acting as a client it registers itself with LS. Topology Service (ToS) is an explicit example of TS, which provides topological information regarding the network accessible to the framework. Resource Protector Service (RPS) is responsible for efficient utilization of resources, especially bandwidth.

The primary perfSONAR services are summarized in table 1.

III. LITERATURE REVIEWS OF PERFSONAR

In this section, I have presented the analysis of work on perfSONAR proposed by various researchers. Andreas Hanemann *et al.* [2] have presented a Service Oriented Architecture (SOA) which supports multi domain measurement performance metrics. With reference to the network monitoring functionality the authors discussed the requirements of various user groups. For example, for a better understanding of performance degradations in the network it is needed to link several information sources. For Network Operation Center (NOC) the framework shall provide a multi-domain perspective on the networks and compare a variety of metrics. For network administrators, a policy could be made that an interface packet drops could be accessed only by NOC staff. For end users, the SOA shall provide timely information to present an analysis of the core/backbone networks which can help to track the exact location of a problem. Regarding the performance of the underlying backbone network, for better understanding of each partner of multi-domain network, a dedicated view of projects spanning over multiple administrative domains is needed. Also, additional metrics (for example, metric presenting the performance of the connections to significant companions/partners) with respect to project link should be offered.

In case of multi-domain network, for tracing the location of the problem (backbone network or local area network), the practice of basic test tools like traceroute and ping, cannot be suitable.

The multi-domain frame work should provide an end-to-end view of the backbone networks to the end users. Web Services only have to be conformant to an XML description, they are independent of an operating systems and programming languages. Hence, the authors in [2] have chosen Web Services to implement their proposed multi-domain network monitoring framework. Multi-domain network monitoring framework is described in section II. The authors concluded by stating the necessity and importance of a network analysis in multi-domain environment.

The data analyzed by network monitoring system should be reused in support of cost efficiency. Ref. [3] introduces the strategy of an integrated network measurement system organized with an initial experiment on the Internet. For active measurement in network, a node dedicated for measurement transmits test packets and the path traversed by test packets is assessed. For passive measurement in network, the characteristics of network usage are determined by constantly monitoring the network traffic. Due to the Internet's wide range applications and distributed administration it is very challenging and inefficient to collect the necessary data at a precise place and time. For constant achievement of the global status and for appropriate and cost-efficient discovery of the causes of network fault degradation, the incorporation of long term measurements, diverse-type, and multiple-location have been considered a key means. The perfSONAR is mainly designed to data sharing across multiple domains. The authors in [3] have developed SequelService module as an addition of the Measurement Archive Service. SequelService module aimed for compliantly browsing the measurement result data stored into the MA generic database interface. The authors conducted the experiments on the Internet and JGN2plus testbed. The authors show the results of available bandwidth of three diverse paths concurrently measured where the observed association may advise the network operator about the underlying site of performance degradation. The authors also claimed that using GoogleMap, the measurement data can be shown on a geographical map. The authors developed a perfSONAR-based integrated network management system for addressing the issues like reliability and availability of multi-domain network, adaptability and flexibility to the requirements of an individual user or application.

Because of increasing traffic on the internet, it is a big challenge in front Internet Service Providers to constantly monitor the network and provide network traffic measurement analysis in terms of reliability, network coverage, spatial and temporal granularity, continuity and detect the sources of performance degradation. Duplicated network traffic measurements result in redundant load on the network. Hence to improve efficiency of the network, network traffic measurement analysis should be shared and reused. The Kastuichi Nakamura *et al.* [4] have developed the system which is written in Perl language and named as perfSONAR-PS which aimed to extend the basis of perfSONAR. The authors have presented, designed and developed an integrated network measurement system based on perfSONAR. Their proposed system directed at "Internet Monitoring as a Service". Their proposed system was designed to accomplish joined unremitting measurement. For example monitoring and analysis of multiple-location, long-term characteristics of the network, flexible information management by supporting diverse granularity in terms of space and time, user-centric information provision by means of unified and standardized API protocols and visualization in an easily understandable form, which depends on the particular user, such as an operator or an application developer. To support number of concurrent users and measurement points, platform independent APIs and GUIs and the competence for international collaboration, their proposed system consists of network information management servers, passive measurement agents and active measurement agents. Their proposed system consist the following policy rules:

- Information storage and measurement must comply with perfSONAR
- perfSONAR PS Daemon should be in functional mode endlessly
- Low cost Linux servers should be used for measurement points and measurement management
- Management authority should be responsible for measurement information, time, and direction
- For detection of an operation system independent user interface, a Web browser should be used as a visualization tool
- Physical network and GPS hardware should be associated with logical hardware
- Management function is necessary for real-time alerts and measurement
- Database distribution independent SQL interface is necessary.

The authors performed the experiments using the measurement points/archive (MPs/MA) located in the Kyushu Technical University network design research center. Through experiments, the authors analyzed the least bandwidth, available bandwidth and decrease in available bandwidth. The authors concluded that their proposed system can be used for Internet Monitoring by the network operators and individual applications/users.

Ref. [5] reviews the significant components of perfSONAR and describes how they are organized by the United States-Large Hadron Collider (US-LHC) community to monitor and analyze networks distributing LHC data from CERN. The authors predict higher-level services. For example, service to locate best replica of file, service to automate the detection of data flows that may need special treatment such as labeling the flows as high or low priority etc. The authors focused on perfSONAR service, perfSONAR-PS.

The LHC data distribution model consists of 11 Tier-1 sites and 140 Tier-2 sites. Each Tier-1 site store and access approximately one Petabyte of raw data per month. The Tier-2 sites play key role in data analysis as these are based at research universities. Data rates with respect to Tier-1 sites will be at least 20 Gbps. The authors have built up pS-NPToolkit by tied perfSONAR-PS tools in a Knoppix-based [6] bootable CD.

For getting functional measurement points, the network operators need to configure the pS-NPToolkit. The main components of the perfSONAR used in present pS-NPToolkit are the data producers, data consumers and discovery. The data producers consist of Measurement Point (MP) and Measurement Archive (MA) which are responsible for exposing performance metrics. Data consumers consist of analysis of clients. Discovery consists of Information Service (IS). IS provides information about existing services and also find associations among explicit network topology elements. IS is responsible for service registration and discovery (Lookup Service (LS)) and representation of network topology (Topology Service (TS)). The network analytical tools provided on the pS-NPToolkit are: Network Diagnostic Tool (NDT) and Network Path and Application Diagnostics (NPAD). Insufficient TCP buffer sizes along network path can be tested by end users using the NDT. NPAD permits users to check local network infrastructure and determine any issues that would unfavorably affect the longer paths. pS-NPToolkit includes the measurement metrics like utilization of resources, discards of packets and many more. Web-based GUI is used to configure perfSONAR PingER-MA to find out other nodes in multi-domain environment. The performance metrics like loss of packets, delay variation, one-way latency are tested using the owamp [7]. Using perfSONAR MA interface, a perfSONAR service perfSONAR-BUOY exposes the owamp data. The perfSONAR-BUOY also used to perform throughput tests using bwctl [8] tool. Through experiments, the authors concluded that using perfSONAR, soft failure problems can be easily revealed. For example, perfSONAR has exposed formerly hidden major bandwidth limiting problems many of which were relatively easily resolved after being identified.

Ref. [9] provides the service of an alarm analysis in hybrid networks for the perfSONAR framework. Their proposed system can be applied in hybrid network, the network which consist IP and optical networks. The authors developed and combined three services of MP to offer an alarm correlation service. The Transaction Language 1(TL1) MP service accepts the alarm from optical equipments, SNMPLite MP service accumulates alarms of routers, and Correlation MP service examines all alarm through the alarm correlation algorithm. The authors use TL1 because it is broadly used to manage network elements in telecommunications and used in optical and broad band access infrastructure. TL1 MP service parse the responses using regular expressions. Using SNMP the authors developed the SNMPLite MP service to collect the real-time alarms from routers. Since their proposed system queries the specific interfaces of router, only SNMP get function in SNMPLite MP service is needed. Cross-layer problems arise in case of hybrid network (IP and optical network) which increases the difficulty of tracing the root cause of network failures. To overcome this, the authors have proposed Correlation MP service which implements the alarm correlation algorithm which considers cross-layer relationships and helps in finding the root causes of the network failures in hybrid network. The authors tested their proposed system in TaiWan Advanced Research and Education Network (TWAREN) which consists of hybrid network comprised with CISCO 7609 IP routers and ONS 15454 optical switches. Using Java program, the authors computed the alarm reduction ratio of their proposed system. Using hybrid network, the authors simulated the scenarios of breakdown in IP, SDH and DWDM layers. The authors compared the correlated alarm amount resulted by their proposed system with original alarm amount. The authors concluded that using their proposed system, 75 percent alarms reduced in IP layer, 86 percent alarms reduced in IP and SDH layers and 90 percent alarms reduced across IP, SDH and DWDM layers. From result analysis of the correlation Measurement Point, the authors have presented the visualization of faulty equipment using perfSONAR UI. The authors claimed that using their approach, the network engineers can find the root cause of the problem in a faster and more accurate manner and improve the network availability.

The authors in [10] have developed the release management process which represents the evolution from the development of services to their utilization and operation on a permanent basis. Using release management process, the authors guarantee the high quality of web services and visualization tools with respect to perfSONAR. The release management aims to assure quality services to the users. The release management of FreeBSD project [11] can be considered as established since it is progressive project. With respect to group definitions, the source code of perfSONAR is publicly available in subversion. It permits for unlimited read access. However, the write access is restricted to supervise the value of code. The steering committee sets some rules with respect to perfSONAR. For example, rules regarding service functionalities, participants in project and the key updation of project. In perfSONAR, the services can be released after individual based testing, named as Micro Releases. After testing of functional and interface specification, installation actions, the Hand Over Process has been installed where micro releases are combined into perfSONAR bundle, named as perfSONAR Bundle Releases. For the hand over, as a prerequisite for the release, the authors have completed several information templates like functional specification, interface specification, installation actions, metadata configuration and sample configuration. The authors ensure high quality of perfSONAR services and graphical tools by providing release management process in perfSONAR. Because of increasing popularity of SOAs, the release management process with micro and bundle releases would be valued participation for related projects.

In the early development of perfSONAR, the authors in [12] provide a way to extend a registration and discovery mechanism, referred to as the “Lookup Service (LS)” to function in dynamic situations for multi-domain network environments. The authors extend the services of LS by taking into account the following parameters: exchange of messages between service peers, sharing of stored registered data and response to queries for distributed information in multi-domain network environment. The exchange of large data sets between "inter-domain" peers and "intra-domain" peers is undesirable.

The authors defined the data summarization procedure in terms of XML Style sheet Language Transformations (XSLT). Their modified LS instances preserve two sets of summaries: an intra-domain summary that reflects the global information view and an inter-domain summary of local peers. To response to a query, first each LS instance must examine locally and if found then the reply will be return else the message will be forwarded to a group leader. Their proposed algorithm dictate membership in peer groups. Actions 1 and 2 of the algorithm invite peers in order to get a response. After establishment of contact, peers lists are updated. Actions 3, 4, 5, 6, and 7 demonstrate how the peers identify the new addition by distributing the information through the overlay. Through experiments the authors have tested their modified extended perfSONAR LS. The authors performed the experiments by joining three LANs via WAN links. The three LANs at the University of Delaware, Internet2, and Lawrence Berkeley National Laboratory. Their experiment examines registration time of a service to single LS to broadcast throughout the two group organizations. The authors show the transmission time of complete summary of services (summary file size ranges from 7KB to 9KB, depending on the installed services and the efficiency of the transformation) in each of the three LAN environments. Furthermore, the authors demonstrate the total time required for information to broadcast on the WAN. The authors concluded that the results are satisfactory in view of bandwidth and latency observations made on the LAN and WAN links. The authors also show the performance of the iterative query scheme. For testing, queries for 50 resources were requested from each domain. The results show that query time will stay similar across domains. Hence, the authors in [12] proved that the summarization will benefit overall query performance across a federation.

Pin-Hsuan Chen [13] recourse to Mozilla Firefox Browser which is an open source project and allows writing plug-in easily. The author has proposed an add-on to Mozilla Firefox which aimed the measuring of Network Performance from an end user's perspective. The author has proposed perfNMS, a novel network measurement system based on perfSONAR architecture. perfNMS accept the request from users, then transfer it into test command, executes the test command and results are returned to users. perfNMS reports the network measurements like end-to-end delay, packet loss, throughput which helps the network administrator to authenticate and mitigate the network problems. Since perfNMS is based upon perfSONAR, the roles of measurement, storage, processing, and visualization of data can be isolated into dedicated service instances. perfNMS can provide services to network end users and individual researchers by providing faster way to access network status and metrics. Further, perfNMS can also provide services to network administrative staff by providing an overview about the network performance and to track long term trends which may helpful to them for network planning and optimization. Measurement Points via NMS add-on from the Measurement layer in the system are responsible for measuring network metrics like packet loss, jitter, end-to-end delay and throughput. perfNMS is written in JavaScript, JAVA, AJAX and XML User Interface Language (XUL). For end-users, the author has provided a simple and easy way to install NMS add-on. A network administrator can assess the servers and network status using ps_NMS UI. The author has implemented the measurement point service (MPS) and measurement archive service (MAS) and claimed that the end-users can get network measurement results in real time with extremely simple and quick way.

IV. SUMMARY OF LITERATURE REVIEWS

In this section I have presented the summary of literature reviewed in section III.

Table 2: Summary of Literature Review

Research Work on perfSONAR	Summary
SOA architecture proposed by Andreas Hanemann *et al.* [2]	In view of requirements of various user groups, the authors have developed and presented a SOA for multi-domain network. Their proposed framework is layered architecture which supports the following functions: • Fundamental network operations for example residual bandwidth, delay, jitter, packet loss • Efficient resource utilization • MAS, LS, TS, AS etc
Development of SequelService module by Kastuichi Nakamura *et al.* [3]	The authors have provided an add-on module named **SequelService** module to the Measurement Archive Service intended for passively browsing the measurement result data stored into the MA generic database interface. Through experiments the authors demonstrate the available bandwidth of three different paths which may guide the network operator about causal site of performance degradation. Their proposed system addresses the following issues: • Reliability and availability of multi-domain network, • Adaptability and flexibility to the requirements of an individual user or application
Integrated Network Measurement System by Kastuichi Nakamura *et al.* [4]	Using Perl language, the authors have proposed and developed an integrated network measurement system based on perfSONAR. Their proposed system supports concurrent users and measurement points, platform independent APIs and GUIs and consists various policy rules. Through experiments, the authors analyzed the least bandwidth, available bandwidth and decrease in available bandwidth. Their proposed system will help the network operators to analyze the bandwidth variation in the network and to locate the site of the network where performance degrades.

Development of pS-NPToolkit by B. Tierney *et al.* [5]	The authors describe how the significant components of perfSONAR are organized by the US-LHC community to monitor and analyze networks by distributing LHC data from CERN. The authors have developed pS-NPToolkit of which main components are the data producers, data consumers and discovery. pS-NPToolkit provides NDT and NPAD, the network analytical tools. Using pS-NPToolkit, the network administrator can analyze the utilization of resources, packets loss, latency etc.
Alarm correlation System by Jen-Wei Hu *et al.* [9]	The authors developed an alarm correlation system for hybrid network (network consisting of optical network + IP network). For optical network, using TL1, the authors have developed TL1 MP service and for IP network, using SNMP, the authors have developed the SNMPLite service. To handle cross layer problems in hybrid network, the authors have developed the co-relation MP service. Through experiments and results, the authors proved that their proposed system shows significant alarm reduction as compared to IP, SDH and DWDM layers.
The release management process by Jeff W. Boote *et al.* [10]	The authors have developed the release management process which ensures high quality of perfSONAR services with micro releases (the services can be released after individual based testing) and bundle releases (micro releases are combined into perfSONAR bundle).
Extended perfSONAR LS J. Zurawski *et al.* [12]	The authors extend the services of LS considering exchange of messages between service peers, sharing of store registered data and response to queries for distributed information in multi-domain network environment. The authors performed the experiments by joining three LANs via WAN links. The authors concluded that their results are satisfactory with respect to following: • Bandwidth and latency observations made on the LAN and WAN links • The total time required for information to broadcast on the WAN • Performance of the iterative query scheme.
perfNMS by Pin-Hsuan Chen [13]	The author has provided an add-on, perfNMS to Mozilla Firefox Browser which permits individual researchers, end-users and network administrators to examine the network performance with respect to packet loss, jitter, end-to-end delay and throughput in real time. perfNMS helps the end-users, network administrators and researchers to troubleshoot and fix the network problems in an efficient and faster way.

V. CONCLUSION

Network reliability is heavily dependent on its infrastructure. It is a common practice to monitor the network within a single domain. However, it is critical to ensure the reliability of end-to-end path across multi-domain environment. perfSONAR is designed by open source community to ensure and monitor the performance of network across multi-domain environment. In this paper I have discussed the importance and review of literature of perfSONAR. Using perfSONAR, soft failures among end to end path across multi domain environment can be locate easily which helps the network administrators to lessen the consequences of network breakdown and improve the network reliability. Further, detailed survey and analysis is required to determine the effectiveness of perfSONAR.

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