Design Requirements for Best Effort Backbone IP Network

Soloman M. Almadi, Ramzi El-Haddadeh, and Masaud Jahromi

***Abstract*—Process control systems for Hydrocarbon Process Automation Applications (HPAA) are implemented in oil and gas fields, plants, refineries, and tank farms in the form of a Local Area Network (LAN) to support control functions. These systems are composed of sensors, actuators, and logic solvers networked together to form a control system platform. Reliable networking plays a key role in supporting such a system infrastructure. The existing network designs consist of multiple, parallel networks with limited interconnectivity supporting different functions. The concept of consolidating HPPA networks on a converged Internet Protocol (IP) and utilize Wide Area Network (WAN) for real time operation was not explored in detail in the past. This paper explores this concept by simulating a WAN network based on Best Effort Quality of Service settings. Simulation and empirical experimentation were conducted to assess the feasibility of such a conceptual design and it showed positive outcomes. HPPA can benefit from a converged IP WAN by minimizing network components and wiring; and provide an integrated control system platform at the end user's desktop.**

***Index Terms*—Bandwidth, best effort (BE), converged IP, quality of service (QoS), peer-to-peer, traffic mix, WAN.**

I. Introduction

Process control systems for HPPA in a Wide Area Network (WAN) is motivated by the increase in technology advancement in networking, which includes high speed Ethernet network, IP QoS design options, and the penetration of standard Ethernet interface into HPAA systems. Moreover, advancement in control systems logic solver, instrumentations, and the concept of distributed intelligence in HPAA systems drive the need for WAN network connectivity. HPAA applications can be in the form of control traffic in a Peer-to-Peer or multi-peer (s) to a master controller. Historically, these applications are based on dedicated and standalone networks with limited interconnection. Non-control applications such as voice, data, and media streaming; are typically supported by a separate infrastructure [1], [2].

The main characteristics of the HPAA LAN network are timeliness, availability, and reliability [1], [3]. These network attributes are essential to provide the foundation for supporting P2P control and safety systems. Timeliness in Process Control System (PCS) for an HPAA application can range from 10ms to 200sec. Hence the network shall be able to support the lower bound of the time delay requirements. Network availability is another key measure. The network has to be close to 99.9999% for safety systems or 99.999% for other HPAA applications. Mix in availability requirements and the result is a network design that must be robust and sustainable at all times. Network reliability is essential in guaranteeing packet delivery and data integrity [1], [3]. Therefore, dedicated and standalone networks were designed and implemented over time to ensure both timeliness and a highly available network to support different process automation segments within an oil and gas plant.

Extensive work was completed on the timeliness of a real time dedicated network in the past. In addition, the network design robustness to ensure a highly available and reliable network was addressed by different network models, topologies and protocols. The concept of using a converged IP network for process control and non-control applications in a hydrocarbon operational Local Area Network environment was explored by the author [4]. Converged IP network for WAN has not yet been addressed. The performance and characteristics of such a network are not defined.

This paper is focused on exploring the BE IP WAN network for supporting both HPAA and non-HPAA applications. Typically, QoS can be based on BE and Priority based QoS settings. BE is where all the applications are allocated a bandwidth based on a weighted average of their traffic size. An application with large traffic demand will acquire more bandwidth than a lower one. Priority based QoS is where each application is assigned a unique priority indicator that governs how the application is treated by the network. Applications with higher priority will be processed faster than lower priority applications.

This paper is organized as follows: Background in section 2. Existing knowledge — by identifying researchers and their approach — in section 3. Discussion, simulation, results in section 4, Conclusion, with possible future work, is outlined in section 5.

II. Background

HPAA provides real-time performance for the infrastructure supporting actual hydrocarbon process operation. This includes oil and gas wells, plants, pipelines network to ship the products to refineries, and tank farms. The overall process includes dealing with hydrocarbon products and their derivatives at high pressure, high temperature, and potentially dangerous processes and unprocessed petrochemicals [5].

By design, each local infrastructure work area (e.g., Process Instrumentation Buildings, shipper pumps yard, product distribution systems, etc.) are supported by a dedicated process control system segments to ensure a local

Manuscript received August 15, 2012; revised October 19, 2012.

Soloman M. Almadi is with Saudi Aramco (e-mail: Almadism@aramco.com).

Ramzi El-Haddadeh is with Brunel Business School

Masaud Jahromi is with Ahlia University.

steady state operation. Output from each process segment is fed-back as an input to either downstream or upstream process segments in a form of feedback control loops [5],[6]. Communication network channels play a key role in such a process control system. The communication channel can span multiple geographic areas in the form of a WAN. Timeliness and reliability are two key characteristics of this network. Conventionally, this network is implemented in a form of a dedicated network design and within a limited autonomous geographic area [4].

III. Existing Research in HPAA Converged IP Network

PCS networks for HPAA have evolved over the past years. There are three different networking layers connecting instrumentation and device level to the control, and then to management information level. Each layer has its level of complexity, expected performance, and unique implementations. The instrumentation and control layers have evolved as a result of development in computing infrastructure and software applications. Wilbanks [2] discussed intelligent nodes (i.e., microprocessor-based communication enabled devices) and their adoption at the lowest layer of process automation instrumentation and control, Fig. 1, in the manufacturing field. Hence, these two layers are now generating more traffic among each other and with their pairs.

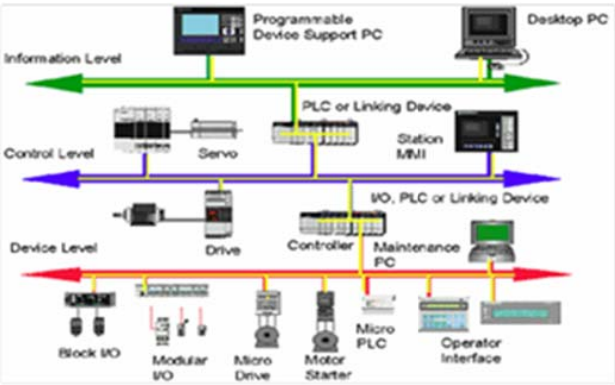

Fig. 1. Process control layers [brooks (2001)]

The HPAA traffic is mostly supported by dedicated Local Area Network (LAN) and some of this traffic is sent over a Wide Area Network (WAN). Cucej, Gliecg, Kaiser, and Planinsic (2004) [7], provided a technology brief of industrial networks and highlighted the different local and wide area networking options. The paper did not provide specifics on the characterization of these different options from an application perspective but highlighted key features such as speed, communication protocol methods, and their physical characteristics (fiber, wireless, etc.). The key challenge when using a WAN network is WAN may expand over many small networks that are interconnected without a uniform Quality of Service design criteria. This condition may create variance in network reliability and timelines especially due to the heterogeneous nature of the WAN infrastructure. New trends in establishing homogenous networks, such as Giga Ethernet, are transforming wide area network to be an optimal communication platform for PCS applications [8].

The benefits of a real-time Giga-bit network can be further maximized when used in a wide area network. Multiple operational plants can be managed from a common command and control center or different control centers that are geographically dispersed; providing backup support for each other when needed [9]. As a result, a distributed autonomous command and control center is formed. This concept can be extensively and effectively used in managing local plant process automation (i.e., within the factory or plant operation field) for different plants apart from each other [10]. This concept is not applied in petrochemical and hydrocarbon (oil and gas) producing operating environments. These different industries typically have a standalone, local real-time network with dedicated controllers to manage a designated process. These networks are typically connected to the information resource planning and management systems located within the operating facility and are seldom connected to each other [10].

IV. Converged IP Network Converged Wide Area Network Best Effort IP Network Simulation

Process control system behavior for HPAA in WAN converged IP network is difficult to predict due to the traffic dynamics and dependency on the underlining network infrastructure and design [4], [5], [6]. Simulation was used to approximate the traffic behavior and network operational environment. Simulation as a research and evaluation method is well used in both academia and industry and has been discussed comprehensively [11]. In this paper, the primary objective of the simulation is to evaluate the PCS behavior utilizing dedicated IP network and benchmark its performance against a converged IP network based Best Effort (BE). BE converged IP was selected for its simplicity and ease of support [12]. The only drawback is bandwidth overhead capacity is necessary to support the anticipated traffic load and possible traffic surge [12].

The OPNET Network Modeler package is selected as the simulation tool for evaluating the concept of converged IP WAN BE [13]. OPNET has extensive use in both academia and industry and as a result has developed its s reliability and reputation [13], [14]. The tool enables the user to build custom applications (e.g., HPAA), network elements (e.g., switches and trunking plan). Moreover, support services such media streaming, IP telephony, and large file transfer can be utilized from the OPNET application library. The tool is used to address cross network traffic for multiple services and provide a holistic performance reporting. Traffic dynamics and network performance parameters such delay, jitter, packet loss, and packet retransmission are tracked and correlated to the traffic load.

In this paper, the simulated WAN network and converged IP services will be exposed to an increase traffic load that increase the overall WAN trunking utilization from 50%, to 80% and then 100%. The HPAA application performance under these scenarios provides the anticipated performance measure for both HPAA and support services.

A. Simulation

First, the custom build for HPAA application need to be

defined to reflect its relationship between the different PCS controllers. This includes the Master Controller to subtending controllers and controller to controller (i.e., Peer-to-Peer relationship). The HPAA PCS controller is defined by the author as part of Almadi, et al., (2010) [4]. The author established the different elements that govern the controller and define internal and external relationships. This definition includes PCS controller processing time, packet size, cyclic period and frequency, and the nature of the TCP and UDP packet characteristics.

The simulated HPAA PCS controller was designed and confirmed based on TCP/IP transport protocol rather than UDP/IP. TCP provides better transmission quality [14] & [15]. The HPAA PCS controller messaging was defined in the form of Request/Request/Response rather than the Request/Response model. The later contributes to additional processing time since the second request won't process until the response for the first request has been received.

B. Simulation Network, Controller and Application Assumptions

In the simulation model, the following assumptions were made for both Wide Area Network and Local Area Network:

1) LAN assumptions are defined as part of Almadi, et al., (2010) [4].
2) WAN network simulation is based defining five different HPAA PCS locations: PCS Area 1, PCS Area 2, PCS Area 3 (Defined as PCS Virtual Center), PCS Area 4, and PCS Area 5.
3) The backbone network, Fig. 2, is based on high speed 1 Gbps Ethernet links connecting each of HPAA PCS location with BE QoS Converged IP network settings.
4) HPAA PCS, voice and video services were simulated along with the injected traffic for loading the network, FTP.
5) Injected traffic was increased systematically with 50%, 80% and 100% utilization

Fig. 2. Process control network simulation model for PCS model

C. Simulation Results

The PCS controller application dynamics were simulated. The focus is to establish a performance benchmark for a dedicated WAN network and compare that to BE QoS Converged IP network. Delay, jitter, retransmission attempts, packet drop, TCP retransmission and TCP retransmission timeout are variable measures that will be utilized in the subsequent sections.

1) Dedicated wide area network

Fig. 3 depicts the application round trip delay between the PCSVC and remote site controllers in the different PCS Areas.

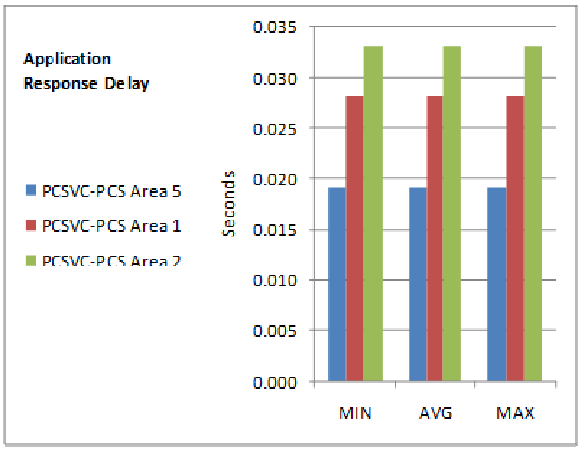

Fig. 3. PCSVC to PCS Areas Controller Application Response Delay

Fig. 4 depicts the IP network delay between PCSVC and remote site controllers in the different PCS Areas. The maximum delay is below 33ms.

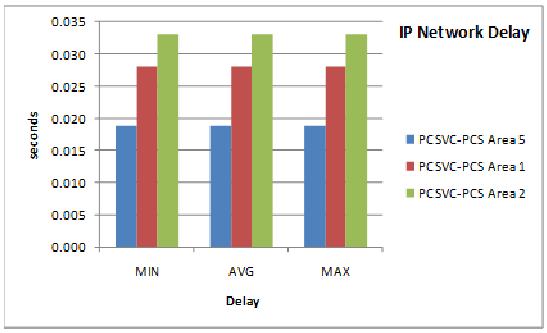

Fig. 4. PCSVC to PCS areas IP network delay

2) Converged IP wide area network

The PCS Virtual Center (PCSVC) has two tightly Controller relationships, PCS Area 1 which is an adjacent node and PCS Area 2 that has at least one hop, a backbone node, in between. Simulated traffic injector was varied at 50%, 80%, and 100% network loading of the available bandwidth (1Gbps). The injected traffic load was triggered at a steady state for 15 minutes of simulation time while the PCS application is communicating to the different PCS elements, intra-node and inter-node. The IP telephony and media streaming are establishing their independent traffic pairing. The PCS application performance for PCSVC and PCS Area 2 is depicted in Fig.5. As noticed the delay was in the order of seconds as a result of the 100% traffic load.

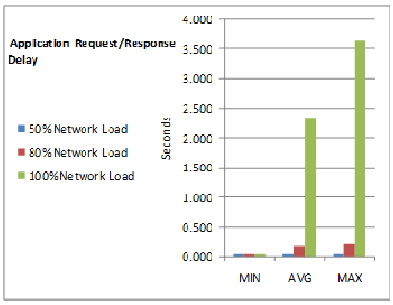

Fig. 5. PCSVC to PCS areas application delay

The IP network delay between PCSVC and PCS Area 1 and Area 2 is depicted in Fig. 6. The maximum network delay,

at 100% utilization, was 300ms. This is followed by the 80% utilization at 266ms. And, 33ms when the utilization at 50%. The 300ms network delay at 100% and 266ms at 80% utilization are considered high and not acceptable.

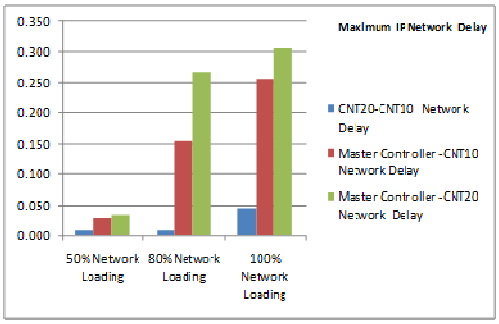

Fig. 6. PCSVC to PCS areas controller IP network delay

Packet delivery integrity was apparently suspected at 100% and 80% utilization since the packet sent and received for the application was not the same. At 50% utilization the packet sent and received are equal. Fig. 7 depicts the simulation outcomes for packet loss for these three different scenarios.

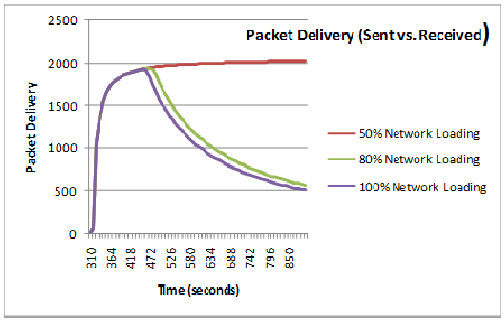

Fig. 7. PCSVC to PCS areas packet delivery integrity

Also, PCS application TCP retransmission timeout was apparent at the 80% and 100% utilization, Fig. 8 The timeout extended over 40 seconds in both network loading. As expected, the 100% loading resulted in an early retransmission rate that started five seconds earlier than the 80% loading. This is an indicator that network congestion build-up is experienced at high network loading.

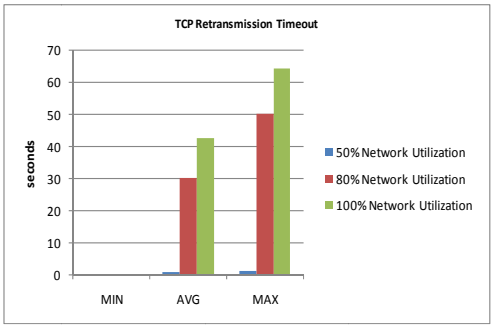

Fig. 8. PCSVC to PCS areas TCP timeout

IP telephony encountered performance degradation as the network utilization increases from 50% to 100%. The IP telephony delay was 765ms at 100% as compared to 730ms at 80% utilization. At 50% the delay was 8ms. Jitter performance was also degraded as utilization increased and was in correlation to delay. At 100%, the IP telephony jitter was at 137ms. At 80% it was at 119ms and 0.028ms at 50% utilization. Table I shows the average delay and jitter at 100% utilization.

TABLE I: SUPPORT SERVICES PERFORMANCE

Support Service Performance (mseconds)	50% Network Load	80% Network Load	100% Network Load
IP Telephony Packet Delay	8	730	765
IP Telephony Packet Delay Variation	0.028	119	137
CCTV Packet Delay	38	1630	1820
CCTV Jitter	2.00E-04	2.00E-03	5.00E-02

3) *Discussion*

Network traffic loading and mix have an impact on the PCS application and network's performance variables such as delay, packet loss, and TCP retransmission. The convention for BE is that each application will get its bandwidth appropriation based on the weighted average that is directly related to its traffic volume. As a result, large file transfer will get most of the bandwidth, as compared to an application in the order of 1024 bytes/second (i.e., PCS). Therefore the PCS application — in a converged IP network — encountered delays that span from 0.28 ms to 4 seconds, depending on the traffic load. Fig. 9 shows the comparative analysis for BE converged IP network at different loadings to the dedicated IP network. The 50% network loading provided a close network performance to the dedicated network. The 80% and 100% show different network.

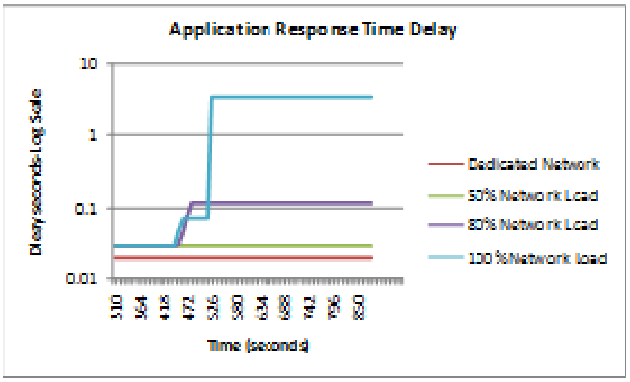

Fig. 9. Dedicated vs. BE converged IP network application time delay performance

The TCP packet retransmission was increased significantly from zero at 50% and 80% load to over 38 counts at 100% during a limited simulation period of 15 minutes. This change is an indicator of the struggle the PCS application encountered during data transmission, when network utilization became high. PCS TCP retransmission is not a favorable pattern and in fact for a safety system, packet retransmission can be used as a threshold to trigger a safe shutdown. Therefore maintaining utilization at a low threshold is essential for a seamless PCS operation.

In addition, support services encountered unacceptable performance degradation at the 80% and 100% networking loading, depicted in Table I.

V. CONCLUSION

Best Effort Quality of Service backbone converged IP network is able to support HPAA and other support services,

such as voice, media streaming, and large file transfer, if the network loading is maintained at 50% or below. The 50% overhead capacity provides the capacity for traffic surge. In addition this overhead capacity may be used during traffic rerouting caused by network outages.

The following are key guidelines to achieve the intended objectives:

1) PCS applications traffic load shall be estimated with at least 20% overhead growth factor.
2) IP telephony and media streaming traffic load shall be projected. Since these services are considered support services for industrial applications, their growth is not dynamic as compared to PCS HPAA application.
3) Media streaming operation is recommended to be on demand service rather than continuous streaming.
4) Design trunking plan to support both traffic surge and traffic reroutes where backbone trunks shall not exceed 50% network bandwidth utilization.

As part of future work, the priority based QoS shall be examined. Furthermore, the impacts of utilizing wireless backbone vs. wired shall be explored.

REFERENCES

[1] H. Shah and S. Spada, "New Generation of Motion Control Networks Fills the Gaps," ARC Advisory Group, pp. 4-22, April 2005.

[2] W. Wilbanks, "50 Years Of Progress In Measuring And Controlling Industrial Processes," *IEEE Control Systems Magazine*, vol. 16, no. 1, pp. 62, 64-66, Febrauray1996

[3] S. Boyer, *SCADA: Supervisory Control and Data Acquisition*, 3rd edn. ISA, 2004

[4] S. Almadi, R. E. Haddadeh, and J. Masaud, "Critical Requirements for Best Effort ConveregedIp Network For Hydrocarbon Process Automation Applications," pp. 189-201, no. 7, 2010.

[5] R. Babatunde, A. Ogunnaike, and W. H. Ray, *Process Dynamics, Modeling, and Control, Book*, Oxford, 1994, 1994ISBN 0-19-509119-1

[6] *Guideline for Safe Automation of Chemical Processes*, AIChemE ISA 84.01 TR-002.

[7] Z. Cucej, D. Gleich, M. Kaiser, and P. Plannsic, "Industrial Networks," in *Proc. of 46th International Symposium Electronics in Marine*, ELMAR, pp. 59-66, June 2004

[8] P. Brooks, "EtherNet/IP: Industrial Protocol," in *Proc. of 8th IEEE Emerging Technologies in Factory Automation*, pp. 1-8, October 2001

[9] C. Brunner, "IEC 61850 Process Connection," in *Proc. of 15th Power Systems Computation Conference*, pp.1-6, 2005.

[10] R. Cabezas, J. M. Selga, and C.Samitier, "A new Generation of Packet Switch Designed for the Integration of Operational Services," in *Proc. of CIGE Symposium*, pp. 1-9, October 1999.

[11] R. Jain, *The Art of Computer Systems Performance Analysis*, New York: Wiley, 1991.

[12] J. Martin, "Managing Best Effort IP Networks over Heterogeneous WANs," in *Proc. of International Working Conference on Performance Modeling and Evaluation of Heterogeneous Networks*, pp. 1-6, July 2004

[13] J. Guo, W. Xiang, and S. Wang "Reinforce Networking Theory with OPNET Simulation," *Journal of Information Technology Education*, pp. 215-226, 2007

[14] S. Almadi, R. E. Haddadeh, J. Masaud, "Converged IP Network For Hydrocarbon Process Automation," in *Proc. of IEEE Second International Conference on Computational Intelligence*, Modelling and Simulation, pp. 1-6, September 2010

[15] S. Almadi, R. E. Haddadeh, F. Askandrani, and M. S. H. Jahromi, "Intelligent Field Converged IP Network for Semi-Real Hydrocarbon Process Automation Applications (HPAA) Case Study," in *Proc. of IEEE International Energy Conference*, Manama, Bahrain, December 18-22, 2010

Soloman M. Almadi Soloman holds a PhD in computing from Brunel University, UK and Master of Science in Electrical Engineering from Southern Methodist University, US, andBachelor of Science in Electrical Engineering fromUniversity of Texas at Arlington, US. He is currently a professional Engineering Specialist in communication, process control systems infrastructure, system integration, and Intelligent Field in Saudi Aramco, Saudi Arabia. He has over 20 years of experience at different capacities in the engineering, planning, and deployment of network and system solutions. Dr. Almadi is a member of IEEE, ISA, and has published several papers in networking, system and process automations, and simulations.

Ramzi El-Haddadeh is a faculty member at Brunel Business School. Prior to that; he was a faculty remember at The School of Information Systems Computing and Mathematics in Brunel University. He is a member of the Information Systems Evaluation and Integration Research Group (ISEing). He has published his work in peer reviewed and well acclaimed journals and international conferences. Dr. El-Haddahehcurrent research interests include Networks operability telecommunication management, ICT adoption and diffusion and information security management in the public sector. He has guest-edited special issues of a number of international journals, and co-chairs a number of tracks at international conferences.

Masaud M. Jahromi was born in Manama-1970. BSC in Mechanical engineering from UOB-Bahrain 1994, MSC in Control and Information Technology from UMIST-Manchester 1996, PhD in Network Engineering from Kent University @ Canterbury-UK 2002. He worked as an Engineer in BAPCO-Bahrain for 6 months (1994). 1996-98 he used to work as a part-time engineer in A-A Computing Company-Manchester. 1998-2000 he used to work as a Lab administrator in Kent university @ Canterbury-UK. Since Feb. 2003 he is an instructor (Ass. Professor) in Ahlia university. Dr. Jahromi'sresearch are mainly focused in Networking, Network-Thinking, Queuing and traffic congestion, Network Security, and ad-hoc networks.