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COMMERCIAL DELAY TOLERANT PERVASIVELY NETWORKED POINT-OF-PRESENCE GATEWAY SYSTEM FOR ISS

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In order to extend and maximize the effective use of the International Space Station (ISS) as a research facility, a transition from a manually scheduled, highly constrained and custom-crafted communications environment to a pervasively internetworked environment is required. Accomplishing such an open networked environment requires the capability of managing key challenges such as security and the quality of service considerations all potential users. These challenges also include the inherent problems of accommodating both delay and disruption in the end-end path between all participating network nodes. This paper introduces the possibility of and examines the potential merit of a technology development mission to research the application of Delay Tolerant Networking technologies to the provide a delay and disturbance tolerant pervasively networked point-of-presence gateway system for the International Space Station.

INTRODUCTION

In order to extend and maximize the effective use of the International Space Station (ISS) as a research facility, a transition from a manually scheduled, highly constrained and custom-crafted communications environment to a pervasively internetworked environment is required. Accomplishing such an open networked environment requires the capability of managing key challenges such as security and the quality of service considerations (availability, performance, resource allocation) across all potential users (government, international, and commercial). These challenges also include the inherent problems of accommodating both delay and disruption in the end-end path between all participating network nodes. This paper introduces the possibility of and examines the potential merit of a technology development mission to research the application of Delay Tolerant Networking (DTN) technologies[1,2,3] implemented in a Commercial Delay Tolerant Pervasively Networked Point-of-Presence Gateway System for ISS.

It is anticipated that such a remotely managed point-of-presence gateway system will be able to significantly enhance the ISS experimentation potential by providing access to network communications resources that are currently unreachable from the ISS. These enhanced networking/communications resources are of demonstrable commercial value, can facilitate the timely and more flexible scheduling of experiment data transmission and ongoing interaction between the crew and/or experiments/payloads both on the ground and in orbit, as well as increase the quality of life on station for crew members by supporting a pervasively networked environment analogous to their terrestrial experience.

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DTN technology provides a tool kit for addressing the delay, disturbance, and intermittency endemic to communications with the ISS due to the combination of it's orbital parameters and the limitations of the communications systems currently accessible. DTN technology seeks to address networks for which continuous bidirectional end-to-end communications paths will often not exist (i.e., intermittent connectivity path defined by geometry and load), where short round-trip packet latency is not possible (i.e., long or variable delay), symmetric data rates are often unsupportable (i.e., most transmissions but not all involve asymmetric data rates), and low error rates are not achievable (i.e. high error rates are common due to the environment, equipment degradation over time/use, pointing/alignment/calibration issues, and transient events). DTN technology involves the characterization of each type of network which may be encountered in the end-to-end communications path, with each required instance being defined as a DTN region. DTN technology introduces a message-switched or "Bundle Layer" between the "Application Layer" and the "Transport/Network/Link/Physical Layer" stack (specific to each DTN region). The Bundle Layer allows source application data packets from region specific "Transport/Network/Link/Physical Layer" stacks to be encapsulated in a common manner (i.e., non-region specific) with the necessary control information and bundle layer header required for managing security and quality of service requirements, as well as the processing instructions for the destination application regarding the user data.[4]

The proffered alternative of a Delay Tolerant Pervasively Networked Point-of-Presence Gateway System for ISS leveraging DTN technology, existing and anticipated operational communications systems (government, commercial, and international) augmented by unique applications of commercial grade hardware/software including open source information technology integrated with real-time knowledge based state modeling & traffic/system management offers compelling advantages if it is viable. The terrestrial use of remotely managed point-of-presence systems in the telecommunications industry, and more specifically in the Internet Service Provider business, is standard practice. The extent to which these systems implement known best practices and make optimal use of state-of-the-art equipment varies substantially. However, maximizing the commonality of components, enabling and facilitating onsite in-situ repair, minimizing the need for incoming spares, managing and reducing power requirements, optimizing packaging, reducing the different types of required spares, managing the system interfaces, monitoring and controlling the environment, maintaining security, optimizing the level of automation and autonomy, as well as characterizing the overall state of the system are integral parts of the trade space in the design of a point-of-presence system regardless of location.

Significant theoretical effort has been invested in the development of delay/disruption tolerant networking architectures, design/implementation of integrated (hardware, software, and functional) operational state models of systems and systems of systems, as well as physical design/implementation of systems optimized for security, availability, performance, and/or resource allocation.[5,6,7,8,9,10,11,12,13,14] Taking these technologies as an integrated set across the classic technology development chasm from relatively low levels of technology readiness to the relatively high levels of technology readiness necessary to garner the support for pervasive integration in flight systems design requires compelling demonstration of their value for any resources committed to their implementation. Indeed the challenges associated with doing so on a generalized basis have been sufficiently daunting therefore most implementations have been point designs implementing only the minimum subset necessary to accomplish the mission objectives. However, the ISS facility already having invested in the necessary characterization of the interfaces (hardware, software, and functional) provides a unique opportunity for use as a high value testbed allowing the integration of DTN protocols with enhanced near real-time operational state models of the systems and internetworking environment, and state-of-the-art high availability plug-in/plug-out hardware/software to deliver functions of demonstrable value that otherwise would not be available. In this case, implementation as a generalized remotely managed point-of-presence system allows for applicability not just to ISS but for an ever widening array of off world missions, as well as terrestrial point-of-presence applications which require remotely managed internetworking.

The recursive nature of the possible interactions implementing such a communications architecture supports the optimal convergence between existing and anticipated systems, commercial/open source information technology, and emerging state modeling/management tools.

One of the near term applications is a proposed project with a commercial customer that wishes to demonstrate that their terrestrial data system resources can be accessed in a satisfactory and sufficient manner to support their effective use from off planet.

Furthermore such effort can grow the community of interest by serving as a model for simplifying payload flight and ground data system requirements thereby driving down communications and networking cost for new experiments/flight projects. This testbed effort can significantly impact other future efforts that are envisioned including facilitating sustained lunar operations, serve as an enabling resource for the Google Lunar X Prize effort, support expanded Space Station Operations, as well as other off-planet applications.

DRIVING REQUIREMENTS

The foundational premise of this work is that there are three driving requirements on information technology systems which apply to both terrestrial and space applications which can be used as the basis for creating a taxonomy to structure and organize data (a collection of symbols) into information (data in context), that can provide knowledge (information in perspective) of the state of a system and the systems/environments which it interacts with. These driving requirements are performance, availability, and security.

- **Performance -** Performance can be defined in the context of information technology systems as the ability accomplish some number of given task at some meaningful level of abstraction measured against preset known standards of accuracy, completeness, cost, and/or speed.
- **Availability -** Availability can be defined as the percentage of time that an information technology system is actually available and capable of performing the tasks it was intended and assigned to accomplish.
- **Security -** Security can be defined as the ability of an information technology system to input, process, transport, and export data, information, and/or knowledge in a controllable manner.

Any viable solution space must address all three driving requirements in order for a system to be both satisfactory and sufficient. For a given system, each driving requirement has some quality of service metric(s) which can and must be defined.

The status quo for systems (terrestrial and space) that are actually tested is a manually scheduled, highly constrained and custom-crafted communications environment. Most other systems are broken at some level with respect to the driving requirements

Such broken systems in a pervasively internetworked environment will become increasingly dysfunctional and ultimately unsupportable. In time all systems that actually matter will have to be engineered to function with the required levels of performance, availability, and security – otherwise such “broken systems” become a threat to others. In practical terms, this means a deterministic, computationally practical, and scalable, near real time state model of the host/source system and the systems/networks that it must or may interact with is required.

ISS COMMUNICATIONS

Current ISS communications capabilities include a limited set of Ku-band, Ka-band, S-band, UHF, and VHF resources used in a combination of space-to-space and space-to-ground modes. These resources are manually scheduled, highly constrained, and function in a custom-crafted communications environment.[15,16,17,18]

As use of ISS expands there is and will continue to be increasing demand for access to additional communications resources with less overhead. Accomplishing such an open networked environment requires the capability of managing key challenges such as security and the quality of service considerations (availability, performance, resource allocation) across all potential users (government, international, and commercial).[19,20]

These challenges also include the inherent problems of accommodating both delay and disruption in the end-end path between all participating network nodes. The dynamic characterization of the networks involved including both their internal performance and inter-network communications interfaces and the ability to correlate the same to established quality of service metrics in near real time is awaiting a satisfactory and sufficient solution.

XROSSLINK INTERNET SERVICES PROTOCOL

It is postulated that a Commercial Delay Tolerant Pervasively Networked Point-of-Presence Gateway System could be built for ISS building using a combination of existing open source resources augmented by a framework for developing and implementing the necessary state/function models (i.e., defined herein as the Xrosslink Internet Services Protocol (XISP)).[21]

The XISP provides a framework for structuring the knowledge set necessary to facilitate required Quality of Service to support system functions (Appendix A, Figure A-1).

Furthermore, by providing a means of clearly delineating interfaces within and between systems and systems of systems it enables practical and pervasive use of existing delay/disturbance tolerant networking tools, other common internet tools, as well as IPsec, DNSsec, and WAVEsec.

As such, XISP supports the development of a wide range of pervasively internetworked environments (near to complex). Near network environments typically being problem spaces which require ongoing confirmation of spacial adjacency/alignment/status of components ranging from very small to potentially very large. Complex network environments typically being problem spaces involving pervasively networked systems and systems of systems.

COMMERCIAL LESSONS LEARNED

An inherent difficulty with the class of problems discussed it that in the final analysis customers do not want or need to know the mechanics below the application layer -- they have a job to do, they just want the technology to work. Accordingly, securing the resources to accomplish work that ultimately the customer really does not want to know about remains a challenge.

In an operational environment that can support the resource overhead application code should be built to defined interfaces. This allows plug-in/plug-out technology and partitioning of code and data.

Furthermore, application processing should not cross interfaces. This simplifies integration facilitates deterministic behavior at both the sub-system and system level.

Application code fails either through single event upsets, storage media failure, introduction of errors and/or unforeseen interactions due to changes, and the potential for gratuitous if not malicious cracking and/or malevolent action by other parties. Accordingly, applications code which is expected to work any appreciable length of time, particularly with respect to mission critical tasks, must be self-healing. This means an immutable reference code base is required which entails both source code and the ability to establish/verify the differences.

All storage media from random access memory to solid state drives fails. Rotating storage media fails more often. Accordingly, all data needs at least a RAID 1 storage environment, which is accessible to each processing point and integral to each gateway/validation point.

Despite the best efforts to characterize normal operations in established situations operational systems typically must accommodate emergent situations which have been found to require at least 100% performance margins for all elements to ensure system stability. Failure to provide such margins run increased risks of potential application failures noted above cascading to higher level system failures.

A tested application that actually works is far more valuable to the end user than any set of untested and/or undelivered enhancements no matter how wonderful their promise – therein lies the fundamental difference between research and production systems.

KNOWN CONSIDERATIONS

Bundle Protocol Considerations

Bundle Protocol (RFC5050, BP for CCSDS) provides a way, though not the only way, to address delay and disturbance tolerant networking issues.[22]

BP unaugmented addresses static cases on a standalone basis, and does not in and of itself have the ability to accommodate a dynamic internetworking environment.

Performance, availability, and security requirements of supported "Functions" must be accommodated by state management processes that work with BP and other processes (e.g., the proposed XISP)

It is postulated that BP + XISP can support a dynamic internetworking environment implementing a wide range of applications.

Link Considerations

A numbers of link considerations need to be factored in to the implementation:

- Keep-alive application traffic can be routed across alternate, including more expensive routes in the temporary absence of Quality of Service (QoS) requirement compliant links
- State, QoS, and Network Model management and application allow for QoS based routing, link administrative considerations, and link availability routing

IPsec Considerations

Internet Protocol Security (IPsec) will be explicitly incorporated as an instance of Openswan a freely available open source implementation. The anticipated IPsec considerations include:

- Outbound End User layer data must be encrypted then passed on for encapsulation in a Quality of Service (QoS) wrapper for Bundle Protocol (BP) processing**,**

- IPsec Security Association keep-alive transmissions are link independent and may be synthesized by the receiving gateway depending on QoS requirements,
- Internet Key Exchange (IKE) with IKEv2 extensions including Session Resumption (RFC 5723)[23] will be incorporated to the degree they are currently supported, and
- Inbound data is decrypted and passed on for use by the End User Layer applications.

Web Services Considerations

Implementation of the proposed gateway system requires the ability to host a range of web services including unsecured (HTTP) and secured (HTTPS).

In order to increase performance and facilitate transactional caching the accommodation of a HTTP/HTTPS Proxy Server is required.

In order to facilitate transactional caching a web page coding scheme extension designed to be compliant with prevailing Cascading Style Sheet (CSS) standards must be defined and implemented. This is intended to allow existing web page code to be augmented with transaction set information where applicable and necessary.

Web pages of interests should be reviewed with sponsoring organizations to identify the screens required for a transaction. This review establishes the conditions which must be meet to proceed with transaction as well as identifying the need for delayed content options. It is possible, in many cases that existing CSS and related code in a website may allow transactional coding to be inferred.

CONCLUSION

A commercial delay tolerant pervasively networked point-of-presence gateway system for ISS can provide a number of useful benefits including:

- cost effective access to additional communication resources for enhanced payload experimentation
- increased quality of life on station for crew members
- ability to cross leverage terrestrial and space technology to accelerate the development and deployment of new commercially valuable as well as mission enhancing / enabling technologies
- simplified payload flight and ground data system requirements

Moving forward with this proposed technology development mission and the results thereof re-quires establishing an engaged community of interest. Such a community should consist of NASA, Commercial, Academic, Non-profit, and International participants.

By engaging both space and terrestrial concerns it is possible to leverage progress in either sector to further the development/maturation of the technology.

There is an effort underway to standup a commercial DTN testbed network to both lower the bar for participation in the community of interest and thereby foster use of DTN technologies.

Xtraordinary Innovative Space Partnerships, Inc. (XISP-Inc) intends to implement a prototype delay tolerant pervasively networked point-of-presence gateway system on the commercial DTN testbed as a precursor activity in support of this proposed technology development mission for the International Space Station (ISS).

The resource environment to support advanced communication technology development on ISS is scheduled to be significantly enhanced in the near term. The Space Communication and Navigation testbed express payload is scheduled to be flown to ISS in late summer of 2012. In addition, in a Fall 2012 timeframe the completion of a series of communication and networking upgrades is anticipated. The use of these additional resources could not only support and facilitate the technology development mission described in this paper, but their presence on station will further drive home the need for a Commercial Delay Tolerant Pervasively Networked Point-of-Presence Gateway System.

The assertion has been made that an implementation of a commercial delay tolerant pervasively networked point-of-presence gateway system consistent with lessons learned from the world of terrestrial information technology could be of material benefit to both payload and other crew operations onboard ISS. The state-of-the-art with respect to implementations of DTN technology, a first order review of the relevant considerations, the availability of the required computational, networking, and communication resources, as well as compelling requirements lend credence that assertion can be credibly tested as a technology development mission on ISS. A mission which if implemented, stands to be of enduring value with respect to facilitating payload operations and ultimately general operations of ISS.

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APPENDIX: A – XROSSLINK INTERNET SERVICES PROTOCOL (XISP)

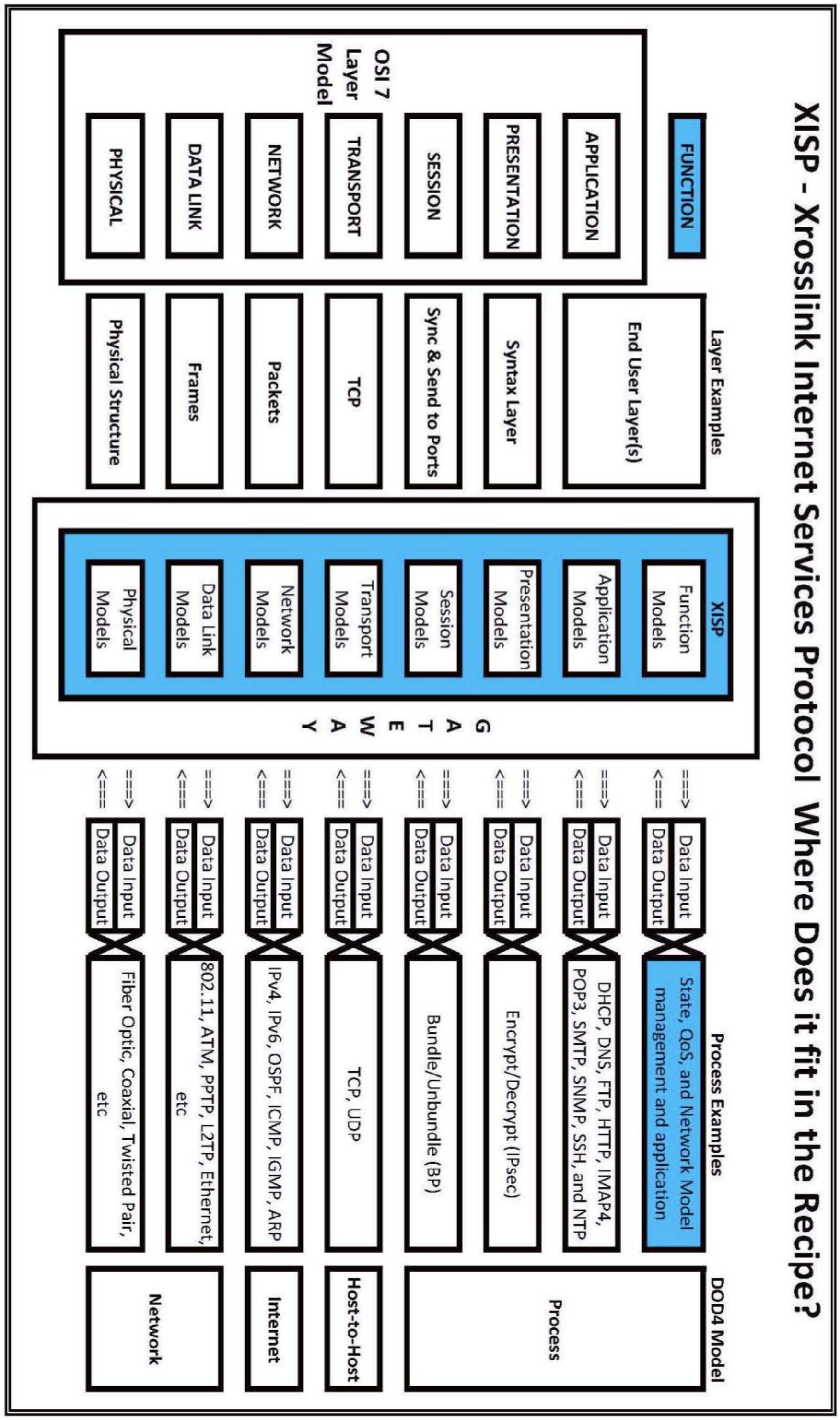

Figure A-1 XISP Xrosslink Internet Services Protocol (XISP)