STANDARDIZED SPACECRAFT ONBOARD INTERFACES

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ABSTRACT

The Consultative Committee for Space Data Systems (CCSDS), an international organization of national space agencies, is branching out to provide new standards to enhanced reuse of onboard spacecraft equipment and software. These Spacecraft Onboard Interface (SOIF) standards will be, in part, based on the well-known Internet protocols. This paper will provide a description of the SOIF work by describing three orthogonal views: the Services View that describes data communications services, the Interoperability view shows how to exchange data and messages between different spacecraft elements, and the Protocol view, that describes the SOIF protocols and services. We will also provide a description of the present state of the services that will be provided to SOIF users, and are the basis of the utility of these standards.

INTRODUCTION

The CCSDS Work Area for Spacecraft Onboard Interface (SOIF) Services is setting out to develop recommendations for spacecraft onboard interfaces [1] [2]. We firmly believe that these recommendations will profoundly affect the development of both the flight hardware and software of future spacecraft. This paper discusses the SOIF activity, detailing its scope, objectives, and the progress made so far.

THE SCOPE OF SOIF

SOIF addresses the data bus communications interfaces onboard the spacecraft, and encompasses the electrical, software, and protocol aspects of those interfaces. In order to limit the activity so that we can generate the first stable recommendations within two years, we are concentrating initially on the communication interfaces between flight units, which include the spacecraft onboard buses, and electrical interfaces to sensors, actuators devices, subsystems, and payload instruments. Our expectation is that, with recommendations on these aspects deployed, support for SOIF will grow and the activity will expand to address other areas, such as the more complex software aspects of these interfaces.

The results of the SOIF activity will be published in the form of CCSDS Blue Book recommendations containing the specifications for the interfaces. Since the scope of SOIF is so large, these recommendations will be published in several parts [3], and projects can elect to comply with one or more parts as appropriate. This allows us to promote a phased adoption of SOIF with some parts of the recommendation being available before others, to simplify project tailoring, and adapt to changes in the future.

Furthermore, there will also be a number of CCSDS Green Books developed, which will provide background and descriptive information. In order to fully understand the SOIF recommendations before implementation, it is best to first consult the Green Books, especially for the Concept and Rationale Green Book [1], and the other

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Green Books listed in that reference.

The Need for SOIF

Standardizing the onboard interfaces, and producing well-structured and comprehensive recommendations should lead to:

- "Plug and Play" for instruments, subsystems, components, devices, and sensors
- Reduced development costs and risks for onboard hardware and software,
- Shorter development times for the spacecraft flight element,
- Shorter spacecraft flight element integration times,
- Shared design and test documentation for spacecraft onboard systems,
- Increased potential for flight equipment re-use,
- Increased potential for flight software re-use,
- Increased potential for test equipment and procedure re-use,
- Potential for improved quality of flight and test equipment,
- Potential for development of standard components,
- Potential for second-sourcing of flight and test equipment,
- Better potential for secondary or "quick-ride" payload development,
- Easier adoption of new and evolving technologies in the future, including hardware and software upgrades, autonomy and vehicle health management.

It is clear from this list that SOIF impacts just about all areas of the development of the flight electronic systems, including both the electronics hardware and the software.

The Objectives Of SOIF

The generation of internationally agreed recommendations and the realization of the benefits listed above are clearly the primary objectives of SOIF. However, there are other objectives that must also be met.

The first of these objectives is to develop a set of SOIF communications services for the users that will meet the specific needs of spacecraft systems. These services (and the elements that support them) will need to meet the needs of the users without excessive overhead or excessive use of resources. This is certainly true of spacecraft, since mass, power, volume, and computational & communications resources onboard spacecraft are always limited.

The second of the SOIF objectives is to select a set of protocols to support the SOIF services that make sense in the spacecraft environment. These protocols will include the popular TCP/UDP/IP protocols (Transmission Control Protocol/User Datagram Protocol/Internet Protocol) [4], but perhaps with a selected set of RFC's (requests for comments). The Space Communications Protocol Standards (SCPS) [5] variation of this standard will also be an option.

The third of the SOIF objectives is to be able to change the underlying data bus to meet the specific needs of a particular spacecraft mission without affecting the implementation of the protocols or the SOIF communications services. In this way, it will be possible to change the underlying data bus without affecting the user applications. It will also be possible to use wireless communications media, and to use the SOIF communications services and protocols to provide seamless communications between nearby spacecraft, such as in constellations, formation flyers, and cooperating spacecraft.

A byproduct of these objectives is that the SOIF standards will enable a capability to move a spacecraft device between different implementations, specifically for space and earth science instruments. SOIF compliant science instruments will be able to move from one SOIF compliant spacecraft to another, even if there is a different data bus implemented on the new spacecraft. This movement of instruments should be possible with only a change in the actual data bus interface card, and the software drivers for that data bus.

Finally, SOIF must be compatible with other, existing standards that are used onboard spacecraft, such as the CCSDS Telemetry and Telecommand standards [6] [7], and the ESA Packet Utilization Standard (PUS) [8].

THREE VIEWS OF SOIF

The preceding sections have painted a rosy picture of the SOIF objectives, but making SOIF a reality, i.e. taking these objectives and turning them into a set of recommendations that can be understood and used in spacecraft projects, requires a well-chosen, pragmatic approach.

One of the main problems is that, because of its broad scope, SOIF is seen as many different things by many different people. For example, spacecraft onboard hardware developers are expecting to see detailed electrical specifications for onboard interfaces. Onboard software developers are looking for abstract interfaces that make it easier for them to access common services for data transfers, device data acquisition and commanding. Spacecraft system engineers are looking for recommendations that will increase the ability to interoperate and to re-use flight components across different platforms. The space instrument (payload) developers are looking for the "Plug and Play" capability that will allow them to move their instrument/payload to another mission with a minimal effort. And project managers are looking for solutions that will save them schedule time and money on their projects, and reduce cost and schedule risks.

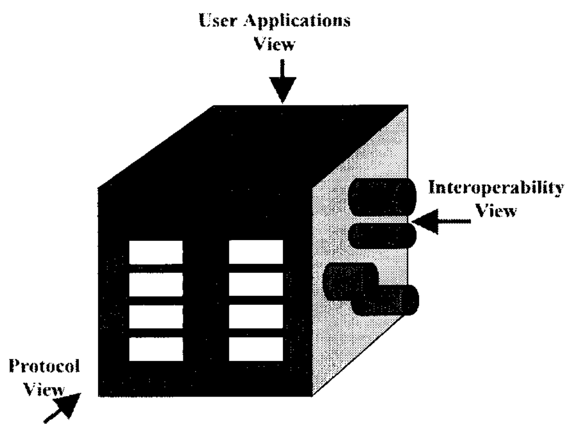

Figure 1 - Three Orthogonal Views of SOIF

All of these views, and many others, must be taken into account in the preparation of the SOIF recommendations, and we are putting a great deal of effort into making the recommendation easily understood by these different communities. The solution that we have adopted is a careful structuring of the recommendation document tree [3].

Another problem that we face, again due to the broad scope of SOIF, is that within this work area we have people with a broad range of skills and specializations. Many of these specializations have their own distinct way of looking at problems, and their own vocabulary for describing things. In order to get the most out of the individual participants in the SOIF work area, we have divided the tasks up into key areas, each of which is addressed by a Working Group or Birds of a Feather group. This new organization within CCSDS (introduced in April of 2003) is similar to the previous SOIF sub-panel organization, and has reduced the need for the Work Area members to become distracted by issues that they are not interested in, and has allowed work on the key areas to be carried out much more efficiently and in parallel with other activities.

The recognition of several views of the SOIF problem domain has been an important step in our standardization activities. Figure 1 shows three orthogonal views of the SOIF problem domain, and discussion of each of these views can give some insight into how the SOIF work area is attempting to accommodate them.

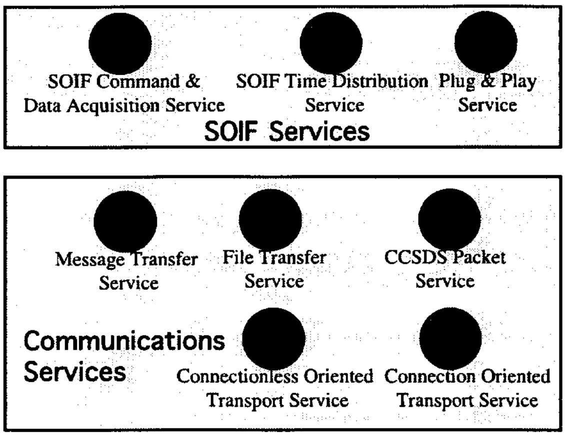

Figure 2 - User Applications View of SOIF Services

The User Applications View

The first view to consider is the user applications view. This is the view of software engineers and programmers developing flight applications for a spacecraft. Since these are one of the most important 'customers' for SOIF, we need to fully understand their view. Typically, application developers see a set of application programming interfaces (APIs), i.e. a set of procedure and function calls, which are shown in Figure 2, that they can bind with their applications to access the services offered by SOIF [9].

From the user application view, not only is the underlying hierarchy not visible, but also is not of interest. Users see only a set of APIs that are uniformly accessible from each application. These APIs correspond to the service access points exposed by the SOIF stack.

The Interoperability View

The second of the three views of SOIF is interoperability. Interoperability is the ability of a device or application to operate with another device or application, where the two devices or applications are both SOIF compliant. This would mean that it would be possible for two spacecraft application to locate and communicate with each other if they are both using SOIF compliant protocols (including Data Link and Physical Layers). This communications between devices would be possible as long as: both of the devices shared a common understanding of the SOIF protocol that flows between the devices, both devices shared a common definition of the functionality that is implemented in each SOIF layer, and both devices used a common PDU to communicate between the two SOIF layers.

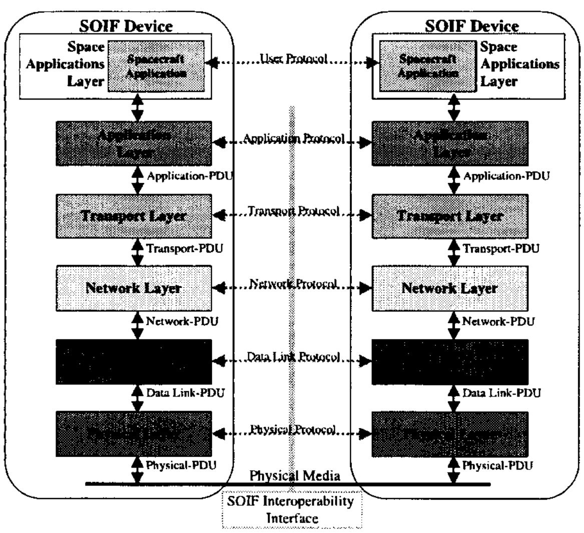

Figure 3 – Interoperability View of SOIF

This concept of SOIF interoperability is shown in Figure 3. This diagram shows how the only physical connection between these two devices will be the physical media between them. The bits of that flow on the physical media between the devices are used to move the encapsulated PDUs from each of the different layers. But across the physical interface, we not only have the indirect physical flow of these encapsulated PDUs, but also an implied direct connection of the protocols between the two different implementations of each layer. So each layer in a device uses the PDU for that layer to transfer the information necessary for the two instantiations of the layer to operate in concert with each other, providing the agreed functionality to move the information from one user to another.

Implied in all of this, it is also necessary for the two spacecraft applications (or two instantiations of one application) to be able to communicate with each other, by having a shared understanding the contents of the User PDU that flows between them, and by using the same functionality and protocol. This will be necessary; otherwise SOIF would accurately deliver messages between the spacecraft applications that could not be interpreted.

The Protocol View

The last view can be called the protocol view, and is shown in more detail in Figure 4. This sees the SOIF problem as being similar to that addressed by classical communication architectures like the ISO (International Organization for Standardization) OSI (Open Systems Interconnection) 7-layer reference model [10], or the Internet protocol stack. Under this view, the solution to the problem is seen as a set of hierarchically ordered services. The key to meeting the SOIF goals of being able to tailor and scale the solution for different situations, and to allow evolution and development in the future, is in the relationships between the services, which are determined by the definition of the service interfaces.

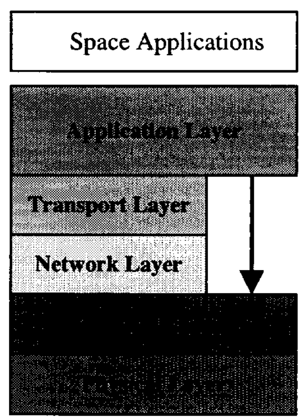

Figure 4 – Protocol View of SOIF

This view is natural to many of the sub-panel members, particularly those who have been involved in protocol design and communication system engineering in the past. It is quite likely that the protocol view will be that seen by the implementers of SOIF, i.e. the engineers responsible for providing SOIF services on a given spacecraft. However, this view is not intuitive to many of the potential users of SOIF, particularly software application developers who write the flight application software, and hardware designers who make hardware interface components.

THE SOIF ARCHITECTURAL MODEL

The SOIF architectural reference model is layered according to the principles of the ISO OSI Reference Model, and is depicted in Figure 5.

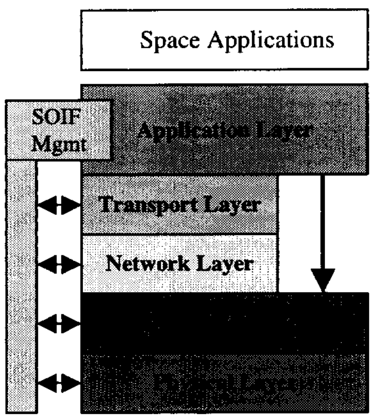

Figure 5 – Simplified SOIF Reference Mode

The SOIF reference model layers differ from the actual layers named in the OSI reference model because we have chosen not to include Presentation and Session layers. The correspondence between the SOIF layers and the OSI layers is shown in Figure 6.

The SOIF space application layer contains user-oriented services that are presented to SOIF users that reside outside of the model. Typically a SOIF user is an onboard application that makes use of the SOIF services to access other onboard applications, and onboard hardware devices (sensors and effectors). This layer does not have an equivalent layer in the ISO 7-layer model, but would be equivalent to a possible eight layer.

The SOIF applications layer provides the fault tolerant message capability that is required by the SOIF services in the space application layer. This layer also provides the fault tolerant file transfer capability that can be used by the SOIF services or the applications. And the applications layer will also have a CCSDS packet service that can be used to move these packets as required. The SOIF application layer is equivalent to the application layer of the OSI 7-layer model.

The SOIF transport layer contains services that enable end-to-end transfer of messages between users. The SOIF transport layer is the equivalent of the transport layer of the OSI 7-layer model.

The SOIF network layer contains services that control the operation of the underlying sub-networks and enable data to be routed throughout the spacecraft network. This layer would also allow data to be routed to where ever it would need to be move. This layer corresponds directly with the network layer of the OSI 7-layer model.

The SOIF data link and physical layers contains services that implement the onboard sub-network and interfaces to other onboard devices, subsystems, and instruments. Typically, onboard sub-networks comprise onboard buses as well as point-to-point links between flight units. The SOIF data link and physical layers corresponds to the data link layer and the physical layer of the OSI 7-layer model.

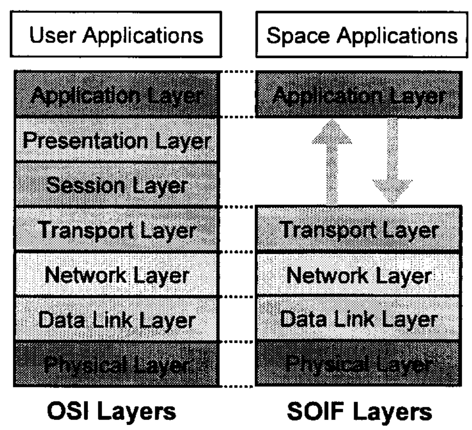

Figure 6 – Comparison of SOIF and ISO Reference Models

The SOIF management service provides the capability of managing the SOIF stack. Because this service is accessed as a user application, and controls the configuration of each layer, it is represented as another user application connected to a vertical slice spanning all of the layers of the reference model in accordance with accepted OSI convention.

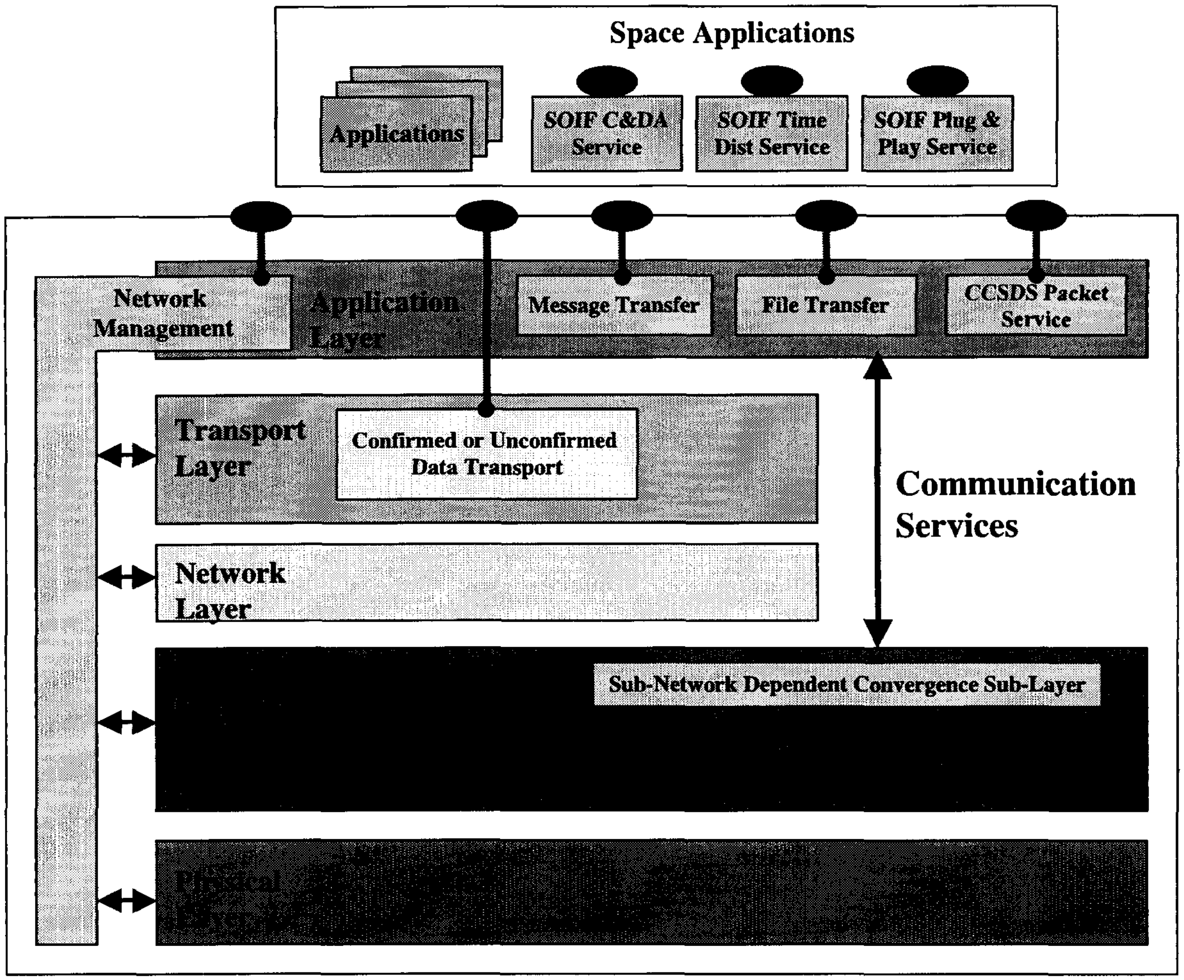

Figure 7 – The SOIF Reference Model

SOIF REFERENCE MODEL

Figure 7 shows the SOIF Reference Model [1]. This figure shows how the SOIF layers relate to each other, and where the SOIF communications services fit within these layers. The access points for these SOIF services are shown in this figure as the ellipses [11].

THE SOIF SERVICES

We are going to be introducing these services by the layer in the protocol stack, as shown in Figure 7. The services are located in the Transport Layer, the Applications Layer and in the Space Applications Layer. There are seven (7) SOIF services that are presently defined and will be available to the users.

SOIF Transport Layer Services

The users will have the ability to directly access the Transport Layer. The services being considered at the Transport Layer will be a reliable (acknowledged) and unreliable (unacknowledged) transport service. In the Internet protocols, these services could be provided by the well know TCP/UDP protocols. The designer may also wish to use an alternate protocol or implementation, such as the Space Communications Protocol Standards (SCPS) [5], which has been optimized for the space-ground communications link, when the spacecraft is in a near-earth orbit.

The Transport Layer interfaces will not always be available because not all implementations will require the use of the Transport and Network Layers. For example, if a spacecraft has only a single subnetwork, then the functionality of these two layers may not be required or implemented. Therefore these implementations do not have these Transport Layer Services available, and it is not possible to use these services as a generic interface.

SOIF Applications Layer Services

As we can see in Figure 7, there are three more data services in the Applications Layer.

Each of these Applications Layer services will provide the same standard interface to all of its users, and can then use all the services provided by the protocol. Otherwise the user will either need to supply the service itself (e.g. reliability, routing, multi-link transparent transport), or do without the service. However, for most applications the use of these higher-level interfaces will provide significant benefits in terms of portability, functionality, and isolation from changes at the lower layers.

Because of this, the Applications Layer services will isolate the details of the underlying data bus from the users. In a later section of this paper we will show how these services in the Applications Layer will provide this isolation.

The Message Transfer Service [9] is used to move arbitrary-sized discrete messages between software processes (users) within the spacecraft, where the user can define the Quality of Service provided by the service (e.g., guaranteed or non-guaranteed delivery). The interface supports both peer to peer and client server interaction models, and provides primitives that can be used to construct basic publish / subscribe interaction pattern if such is desired. The basic elements of this include: name and address resolution, connection establishment, synchronous and asynchronous message transfer mechanisms, and synchronization mechanisms for cooperating processes. Mechanisms are also provided to enable discovery of available Quality of Service (QoS), to select QoS, and for error reporting and service monitoring suitable for operation in a space environment.

The File Transfer Service is used to move files between users onboard or within the vicinity of the spacecraft. This data structure would be preferred in a number of cases, such as a complete set of related scientific observations (telemetry), a set of commands to a particular destination, or a patch or update to the flight software for a particular instrument or subsystem.

The CCSDS Packet Service is the final of the three services, and is specifically used to move CCSDS Packets around the spacecraft at the Applications Layer, as maybe required by some users. This format is particularly useful because some Space Applications Layer services are specifically designed to operate with data in this format. The European Packet Utilization Standard (PUS) [8] is perhaps the most popular of these Space Applications Layer users, even to the point that a standard for this service has been created for use by the European Space Agency.

SOIF Space Application Layer Services

And in Figure 7, we can also see that there are three other SOIF services in the highest of the layers, the Space Applications Layer. The Space Applications Layer services use the Applications Layer services to move data around the spacecraft.

The Command and Data Acquisition Service (C&DA) is used to provide low overhead access to read data from spacecraft sensors and to also provide low overhead commands to spacecraft actuators. A central aspect of this service is that it will be able to provide access to any sensor or actuator, no matter where on the spacecraft (relative to the user) that the sensors or actuators are located.

There are six capability sets that make up the functionality of the C&DA service, and they are as follows:

> Device Access: where a user-supplied logical address of the device is converted by the service into a network address, allowing the device to be accessed from anywhere in the network.
>
> Engineering Unit Conversion: which will convert the binary value obtained from reading the device into the engineering units of the measurement. In other words, by using this capability, the user will be reading a temperature, voltage, or pressure, instead of receiving a raw number in which the user must make this conversion.
>
> Data Product Acquisition: where data from multiple sensors can be read from a single access, and simple calculations can be made from these multiple readings.
>
> Data Monitoring: the requested data is monitored against declared limits (for example red-line and yellow-line limits) and only reported to the user when the data goes outside the limits.
>
> Device Virtualization: devices are read and

controlled using a virtual generic device image, or model. Models can also be used to control more complex devices, such as a reaction wheel.

Data Pooling: where the Data Pooling function performs a periodic read of the sensor data, and places the most recent into a data pool (data base). The user can access the periodic data from the sensor data pool or database, and will access the most recent data.

The Time Distribution Service allows users to obtain a time value that is correlated with the centrally maintained spacecraft onboard time. This service is also used for distribution of time from a central spacecraft clock to any distributed clocks that may be located in different elements of the spacecraft avionics. However, the methods that are used to keep the central spacecraft time synchronized to the ground or control center are beyond the scope of this SOIF Time Distribution Service.

The Plug and Play Service is the newest addition to the SOIF Reference Model. Indeed, the Plug and Play Service is so new that this discussion is still somewhat speculative. However, much of our user feedback has requested this type of service, so it will be included herein.

It is intended that the Plug and Play service provide a capability to allow software components, complex instruments, and subsystems to be dynamically inserted into the spacecraft while it is operating. This will allow, for example, software upgrades to take place in a running system, a new instrument to be inserted during spacecraft integration, or a spare instrument to be powered up and brought into operation during the course of a mission.

ACCESS TO THE DATA LINK LAYER

Figure 7 showed the SOIF Reference Model, and we have briefly mentioned how the services in the SOIF Application Layer can be used to isolate the user applications from the underlying data bus. This section describes in more detail the alternate implementation approaches that may be taken.

For this discussion, we will assume that all users from the Space Applications Layer will access the lower layer communications by way of one of the three Application Layer services: the Message Transfer, File Transfer, or CCSDS Packets services.

Figure 8 illustrates two alternate protocol paths down the stack that the service implementation may take to the Data Link Layer. The path of the arrow on the right shows the case when there is only one subnetwork (data bus) onboard the spacecraft. This means that there is not only one type of subnetwork, but there is only one physical subnetwork on the spacecraft.

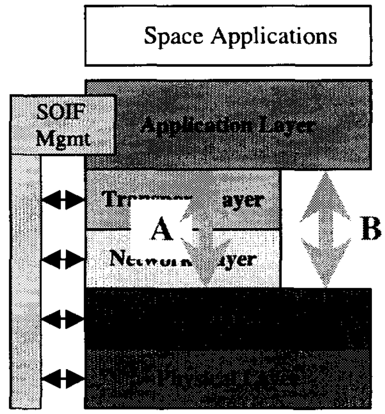

Figure 8: Access to the SOIF Data Link Layer

The arrow on the left in Figure 8 shows the other case, when there are multiple subnetworks available to the spacecraft. In this case, it will be necessary to implement the Transport and Network Layers, in order to provide the functionality of these layers across the multiple subnetworks. In this case, there can be several subnetworks on the spacecraft, and they can even be of different types. It is even possible that a spacelink subnet (RF) can be used to connect two different spacecraft, if they are close enough for the Transport and Network Layer protocols to still work.

In either case, the services in the Space Application and Applications Layers isolate their user from which protocol path through the stack is used for a particular implementation/deployment.

The implication of this discussion is that SOIF will be able to deliver on its promise for interoperability. With all of the users (be they subsystems, instruments, or hardware devices) using the SOIF Space Applications and Applications Layer Services, the users can be interchanged at will. Similarly, it will be possible to change out the underlying data bus without any effect on the users. Or, it will be possible to move a user from one spacecraft (for example if it has only one data bus) to another spacecraft, (even if it has multiple data busses, and none of them use the same data bus technology as the first spacecraft) without effecting the user implementation.

Of course, the effect on the overall system must still be accounted for, e.g. an increase in bus utilization. However, through the use of such standard services, it should be simpler to characterize these parameters, and hence determine the resulting performance of a system being designed from re-used user components and SOIF services.

CONCLUSIONS

SOIF is a very active, international initiative by the CCSDS and fully supported its sponsoring agencies and industry to define standards for spacecraft onboard interfaces. This work has a very broad scope, and is likely to have a beneficial effect on many aspects of spacecraft onboard systems in the future. Within the space of this short paper we have only been able to give a brief introduction to SOIF and its progress so far.

Ultimately, this flexibility of SOIF to operate in any number of different interoperability scenarios will be very important in the ultimate acceptance of SOIF in the larger spacecraft community. As these capabilities are diffused throughout the industry, we can expect that SOIF will start to bring increased levels of cost savings and reduced risk to a large number of different missions. Indeed, we in the SOIF Work Area believe that once SOIF is well known and understood, these recommendations and their successors will be the dominant spacecraft interface technology for the next few decades.

We apologize to many of our SOIF colleagues for not having featured some of their activities, particularly relating to the SOIF network management. This has been due only to a shortage of space. These and other aspects of the SOIF work will be published in the future.

ACKNOWLEDGEMENT

SOIF is a collaborative activity involving many individuals from different countries and organizations throughout the world. We gratefully acknowledge all of the contributions of the SOIF work area members during the twice-yearly face-to-face meetings, and the numerous teleconferences and e-mail exchanges that have brought us so far.

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ACRONYM LIST

API:	Applications Programming Interface
C&DA:	Command and Data Acquisition
CCSDS:	Consultative Committee for Space Data Systems
ESA:	European Space Agency

FDIR:	Fault Detection, Isolation, and Recovery
IP:	Internet Protocol
ISO:	International Organization for Standardization
OSI:	Open Systems Interconnection
PDU:	Protocol Data Unit
PUS:	Packet Utilization Standard
RF:	Radio Frequency
RFC:	Requests for Comments
QoS:	Quality of Service
SCPS:	Space Communications Protocol Standards
SIG:	Special Interest Group
SOIF:	Spacecraft Onboard Interface
TCP:	Transmission Control Protocol
UDP:	User Datagram Protocol