Standardization Activity for Spacecraft Onboard Interfaces

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Abstract—The Consultative Committee for Space Data Systems (CCSDS) is an international organization of national space agencies that is organized to promote the interchange of space related information. CCSDS is branching out to provide new standards to enhanced reuse of spacecraft equipment and software onboard of a spacecraft. This effort is know as Spacecraft Onboard Interface (SOIF). SOIF expects that these standards will be well used within the space community, and that they will be based on the well-known Internet protocols. This paper will provide a description of the SOIF work by reviewing this work with three orthogonal views. The Services View describes the data communications services that are provided to the users. The Interoperability view provides a description to users on how to use SOIF to interchange between different spacecraft data busses. And finally, the Protocol view, describes the protocols and services that are to be implemented in order to provide the users with the advantages of the SOIF architecture. This paper will give the reader an excellent introduction to the work of the international SOIF team.

Table of Contents

1. Introduction

The CCSDS P1K Subpanel for Spacecraft Onboard Interfaces (SOIF) 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 electrical and communications interfaces onboard the spacecraft, and encompasses the electrical, software, and mechanical 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.

[1] 0-7803-7651-X/03/$17.00 © 2003 IEEE
[2] IEEEAC paper #1263, Updated 20 November 2002

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, 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.

The Need for SOIF

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

- "Plug and Play" 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 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 element electronic systems, including both the electronics hardware and the software.

2. 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 three primary 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), but perhaps with a selected set of RFC's (requests for comments). The Space Communications Protocol Standards (SCPS) [3] 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 "Plug and Play" capability, 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.

Continuing, there are a number other objectives that must be considered as part of SOIF. First, SOIF must not constrain the spacecraft implementer unnecessarily. This means, for example, that SOIF must not limit the implementers' choice of onboard bus, or constrain him to use a particular programming language or operating system. Also, while SOIF will recommend the use of certain communication protocols, and will define the implementation profiles of those protocols, it will not preclude the use of different protocols that can be integrated within the protocol stack.

Second, SOIF must be appropriate for several future generations of spacecraft. This means that it must accommodate the needs of the next generation of spacecraft, which can be determined fairly accurately, as well as the needs of spacecraft far in the future, which are much more difficult to determine.

And third, the cost of compliance for early adapters must be kept to a minimum so that their cost of adoption will be lower than their added cost of adopting the standard. Obviously, the adoption of any standard will impose some cost penalties on the first projects to adopt the recommendations. To keep the costs of compliance as low as possible requires that early users get adequate support, and that component and instrument developers are encouraged to adopt the recommendations for their products.

Finally, SOIF must be compatible with other, existing standards that are used onboard spacecraft, such as the CCSDS Telemetry and Telecommand standards, and the ESA Packet Utilization Standard (PUS) [4].

3. 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, onboard time distribution, and 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 “Plug and Play” capability. And project managers are looking for solutions that will save them schedule time and money on their projects, and reduce development risks.

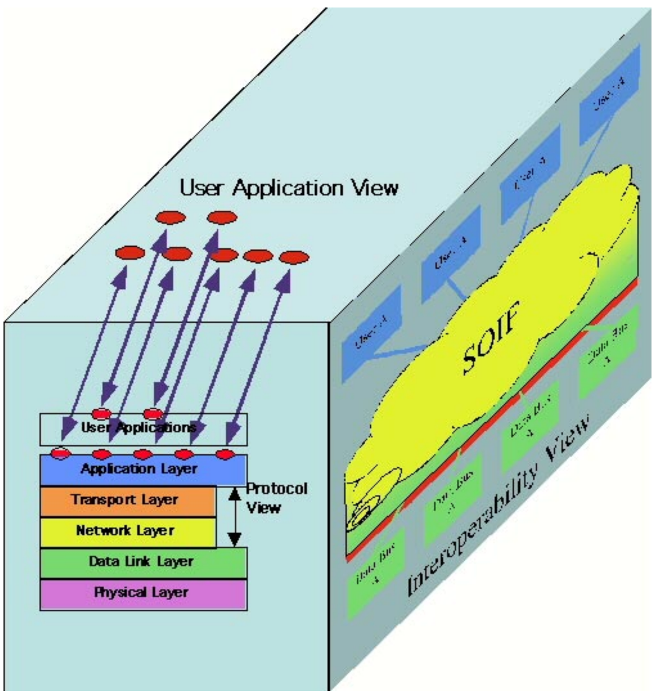

Figure 1 - Three Orthogonal Views of SOIF

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.

Another problem that we face, again due to the broad scope of SOIF, is that within the sub-panel 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 on the sub-panel, we have divided the tasks up into key areas, each of which is addressed by a Special Interest Group (SIG), i.e. a small group of individuals with a special interest in that area. This has reduced the need for sub-panel 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, and one that we are only just coming to terms with. 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 sub-panel is attempting to accommodate them.

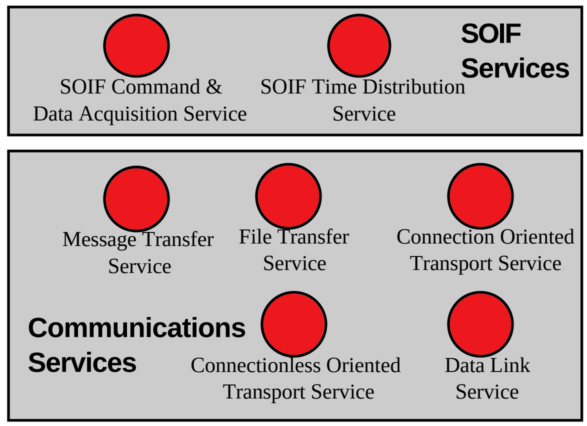

Figure 2 - User Applications View of SOIF Services

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 that they can bind with their applications to access the services offered by SOIF [5].

From the user application view, the underlying hierarchy is not only not visible, but 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 vocabulary associated with this view includes expressions such as *API*, *bind*, *procedure call*, *function call*, and so on. This services view of SOIF is shown in Figure 2.

The Interoperability View

The second view that is considered is the interoperability view, which shows how the SOIF standards can be used to insure interoperability. This view is concerned with how a SOIF compliant device or subsystem can be attached to any supported underlying bus with a minimal amount of change. This is shown in Figure 3 as the ability to change out the bus without effects on the protocols (in the protocol views) or the provided services (in the User Applications view). Implementation of this view will also allow the SOIF compliant spacecraft to easily implement gateways between different types of data busses, if this is required.

This is the view generally adopted by the avionics hardware engineers, who are concerned with the implementation of the avionics data bus, and how the data bus can be changed to meet the needs of the particular mission.

The Interoperability View is also concerned with how a user application can interface to the SOIF services. However, this was covered in the previous discussion of the User Application View, and will not be discussed further here.

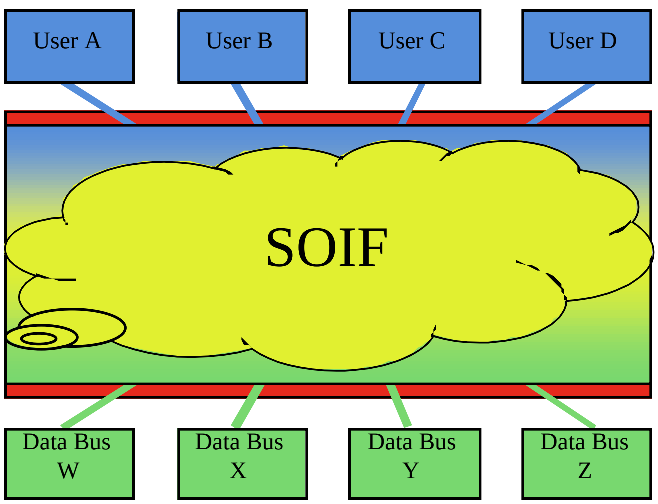

Figure 3 – Interoperability View of SOIF

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 [6], 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.

The vocabulary associated with this view is that of OSI and the internet community, and includes words and phrases such as *service*, *hierarchy*, *service access point* (SAP), *grades of service*, and so on.

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.

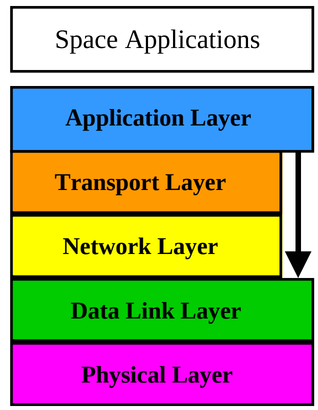

Figure 4 – Protocol View of SOIF

4. THE SOIF DOCUMENTATION TREE

All of these views are important, and all of them are now being taken into account in SOIF. Since SOIF is ultimately deployed as a recommendation, or in fact as a set of recommendations, the document tree that is shown in Figure 5 is extremely important. This structure determines how easily different potential users can understand SOIF, and how readily they can adopt the elements of the recommendation that are appropriate to them. The principal documents published by CCSDS are green and blue books. Green books describe concepts and rationale, and are informative. Blue books contain the actual recommendations, and are therefore the normative documents of CCSDS. Prior to being finalized and approved, blue books are published as red books. The proposed structure of the SOIF document tree is shown in Figure 5. Under this scheme, a single green book called the SOIF Concept and Rationale describes the basic concepts behind SOIF and explains how SOIF can be used on a project. Beneath this there is a series of green books describing the concepts of the key components of SOIF in more detail. Finally, beneath these are the red (draft recommendations) and blue books that make up the normative part of the recommendation.

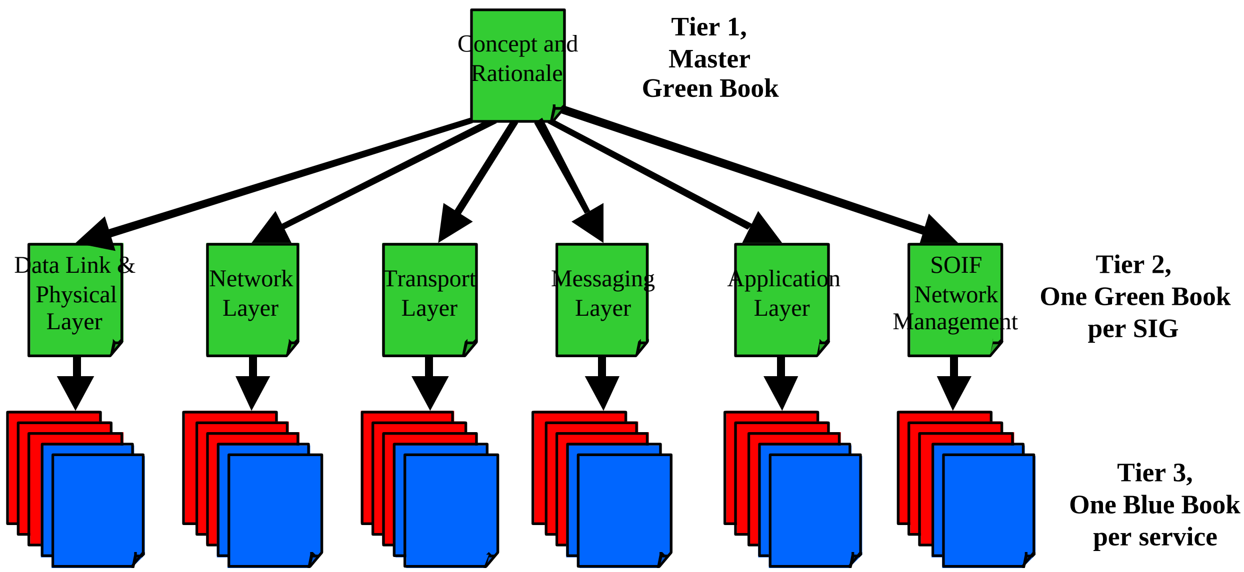

Figure 5 - The SOIF Document Tree

5. 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 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 sensors and actuators. The SOIF application layer is equivalent to the application layer of the OSI 7-layer model.

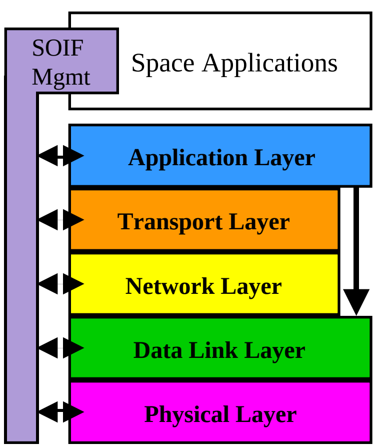

Figure 6 – Simplified SOIF Reference Model

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.

The SOIF ***transport layer*** contains services that enable end-to-end transfer of messages between users. The SOIF transport layer contains 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 corresponds directly with the network layer of the OSI 7-layer model.

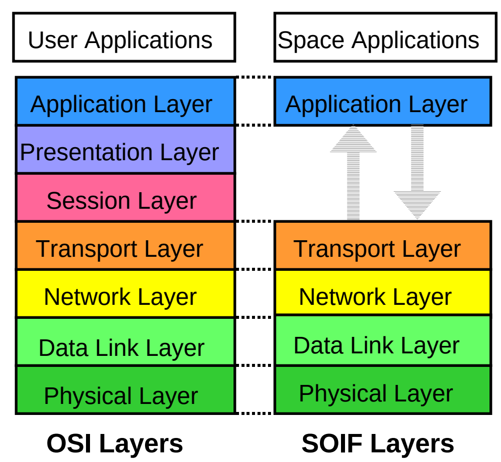

Figure 7 – Comparison of SOIF and ISO Reference Models

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.

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.

The SOIF reference model layers differ from the actual layers named in the OSI reference model because we have chosen not to include certain layers. The correspondence between the SOIF layers and the OSI layers is shown in Figure 7.

6. THE SOIF SERVICES

Having established the SOIF layers, these have now been populated with a number of services that are needed onboard a typical spacecraft. These are shown in Figure 8.

SOIF Services by Layer

There are six (6) SOIF services available to the users that are presently defined, and they provide access to four different SOIF layers.

In the Space Applications layer, these services are:

- Command and Data Acquisition Service (C&DA), which will provide low overhead access to read data from spacecraft sensors and to also provide low overhead commands to spacecraft actuators.

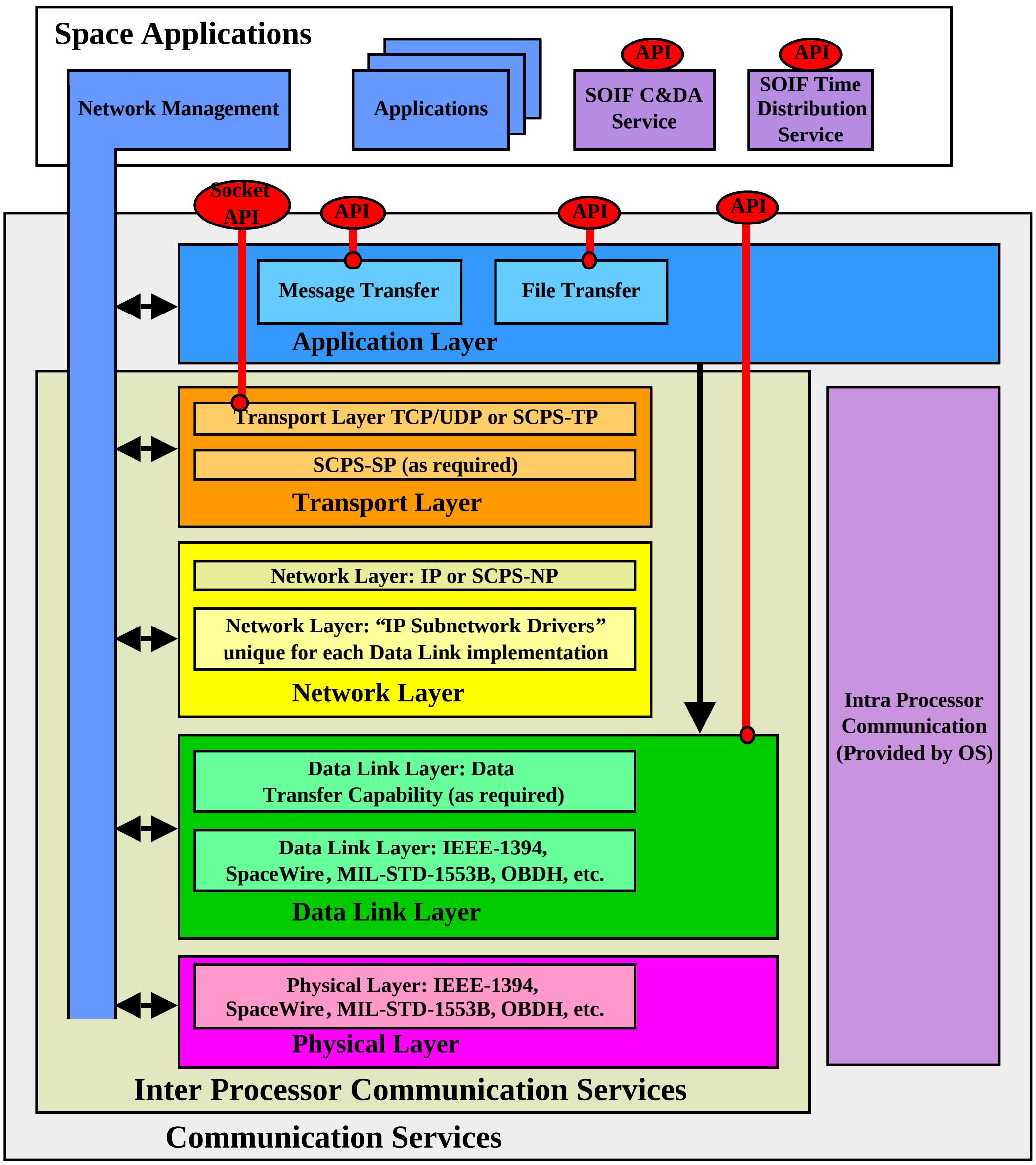

Figure 8 - SOIF Services and Protocols

This service provides six (6) sets of capabilities for its users, which will be described later.

- Time Distribution Service, which is used for distribution of time from a central spacecraft clock to the distributed clocks, located in different elements of the spacecraft avionics. These services keep various spacecraft clocks properly synchronized.

In the Applications Layer, there are two other data services that are used by the Spacecraft Applications and the SOIF C&DA and Time Distribution services to move data around the spacecraft as needed. These services are:

- Message Transfer Service [5], which is used to move messages around the spacecraft, where the user can define the quality of service provided by the service, and

- File Transfer Service that is used to move files for the users.

The users can also directly access in the Transport Layer:

- Reliable (acknowledged) and unreliable (unacknowledged) transport service. In the Internet protocols, these services could be provided by the well know TCP/UDP or similar protocol.

And finally, for legacy users who have applications that are designed to directly access the Data Link Layer of the underlying data bus, there is one final service:

- A Data Link Service which allows the legacy user to operate without changes

However, the CCSDS SOIF subpanel cannot recommend this Data Link Service. Using this service means that this application will not be able to take advantage of any of the SOIF capabilities.

Using SOIF Services

Users of the SOIF services will be software applications that are located in the Space Applications layer. These users include the Network Management application that is defined as part of SOIF. These users can access any of the SOIF Services. For the purpose of this discussion, we will assume that they are using the C&DA service. The activities that occur are:

- The user will access the C&DA API. The C&DA service will process the request as discussed below.

- The C&DA service will access the Message Transfer API to provide fault tolerant real-time message transfer.

- The Message Transfer will access the Transport Layer service that is required. Between TCP and UDP, the C&DA service may use UDP.

- If there is more than one subnetwork within the local addressing space, then IP can be used to determine the subnetwork to which the accessed device is attached, and determine the proper routing to that device.

- The IP drivers will provide the proper interface to the underlying subnetwork. These drivers will hide the unique qualities of the underlying data bus from the protocols, services, and users.

- The message will be sent to over the data bus, by sending the message to the data link layer.

The C&DA Capability Sets

The SOIF Command and Data Acquisition Service is made up of six different sets of capabilities. Each of these capability sets is discussed below.

The capabilities that are provided in each of these capability sets are used to isolate the user from the actual hardware sensors and actuators. This separation will enhance the reuse of the software, and will enable quicker development and test of the sensors and actuators, and the applications software that use them.

Device Access—For this capability, the logical name of the device is converted into the proper hardware address, which can be used to access the device on the proper subnetwork. Therefore, the user is no longer concerned with the details of the device location.

Engineering Unit Conversion—When a sensor is read, the hardware will read a digital number, which is physically a voltage. This digital number will be converted to engineering units, which may be a volts, amperes, Newton per square meter (for a pressure), or degrees centigrade.

Data Product Acquisition—Data from multiple sensors can be access from a single data request. These data can be processed to create a single data value from the multiple readings. The reading of voltage and current to calculate the power would be the simplest example of this capability.

Data Monitoring—This capability would be used to provide periodic reading of a sensor's data value. Data from this periodic reading could be compared to one or more limits, thus creating the ability monitor the data points against redline or yellow line limits.

Device Virtualization—The C&DA service will assume a generic virtual device or device model when it is used to access a device of a certain type. The user will assume the C&DA virtual device model, and the device virtualization capability will convert commands and data into the commands and data needed by the actual device.

Data Pooling—Periodic reading of the device by the Data Monitoring capability can be sent to this capability, where a pool or database of data from the device can be stored. In this way, the user will access the data pool, being guaranteed that it will receive the most recent data from the device.

7. 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.

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

8. 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 sub-panel members during the twice-yearly face-to-face meetings, and the numerous teleconferences and e-mail exchanges that have brought us so far.

Some of the work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

9. References

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10. Authors

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11. ACRONYM LIST

API: Applications Programming Interface
C&DA: Command and Data Acquisition
CCSDS: Consultative Committee for Space Data Systems
IP: Internet Protocol
ISO: International Organization for Standardization
OSI: Open Systems Interconnection
PUS: Packet Utilization Standard
RFC: Requests for Comments
SAP: Service Access Point
SCPS: Space Communications Protocol Standards
SIG: Special Interest Group
SOIF: Spacecraft Onboard Interface
TCP: Transmission Control Protocol
UDP: User Datagram Protocol