Solar System Wide Data Network

George R Tyson[1]
BNRC LLC, Colorado City, Texas 79512, USA
gtyson@bnrc.tech

As humanity expands into the solar system all types of data will be crucial to the success of the endeavor. A Solar System wide data collection, analysis and dissemination network similar to the terrestrial Internet of Things (IoT) or Industrial Internet of Things (IIoT) must be constructed. Multiple issues must be considered including concerns with distance, interference and timing along with the advantages that include economic returns. By extrapolating the developing terrestrial IoT network to a Solar system wide net and the examination of issues and advantages, a basic eight point development philosophy can be determined.

I. Introduction

A key component of civilization is shared knowledge communicated through data. Since the dawn of time, humans have transmitted information essential for survival, such as hunting locations, cooking techniques, building methods, and the warnings of dangers. Initially data was conveyed by voice and hand signals and later through writing. The speed of data dissemination was limited by the speed of personal travel.

Early efforts at transmitting data more rapidly than available transport include signal fires, smoke signals, telegraph and early radio. All of these attempts suffered from (in today's parlance) low bandwidth and speed. A limited amount of data could be sent over long periods of time. While the speed may have been a significant improvement over available transport it would be difficult to impossible to transmit the encyclopedia Britannica using these methods.

Humans eventually developed methods that can communicate large volumes of data at near light speeds. The internet is a good example. We can use our favorite search engine and find a plethora of information on almost any subject. We can also be entertained by endless video and audio content along with games that have people playing together from all over the world. The acquisition, storage, analysis and sharing of data has now become a cornerstone of human civilization.

Science and engineering, which have been major forces in the advancement of civilization, use the acquisition, storage, analysis and communication of data extensively. It has become so prevalent that we have created labels for it. The Internet of Things (IoT) is applied to systems that are more consumer oriented while Industrial Internet of Things (IIoT) tends to be applied to more professional systems. For the purpose of this essay both systems are considered identical and will be referred to as IoT.

II. Internet of Things

The purpose of an IoT system is to control a process through the collection, storing and analysis of data. The result is used to make informed decisions on how to improve processes, ensure smooth process flows and to illuminate new methods. The decisions and control can be done by Humans, A.I. or a combination of both. The unique part of IoT as compared to other data systems is that it is decentralized. Users and data do not, and in most cases are not, located in the same area. Systems located in remote areas can be monitored and controlled from anywhere in the world by authorized personnel. This allows experts to examine and control systems without having to travel to where the system is located.

IoT in its most base form collects data from a system, transfers it over the internet to a server system (cloud) where it is stored, analyzed and then accessed by any user device that is connected to the internet. An IoT system can also work in the reverse and affect a system by having a user or A.I. send commands through the internet to a device in the field. The data can take any number of forms including binary, text, audio or video. Consumer examples include smart

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[1] Manager.

refrigerators that will send you a notice or order an item when it gets low. A car that can be started and have the A/C or heater turned on by an app on your phone. Even streaming services such as Netflix are all examples of consumer IoT.

Commercial examples include automated factories that can be monitored and controlled remotely. An example would be monitoring fluid levels in storage tanks and controlling valves and/or pumps remotely by an A.I. and /or humans. Complete assembly lines can be monitored and controlled through an IoT network providing the ability to adjust to a changing market demand or supply issue. Even the remote monitoring of hazardous areas or processes can be done safely through IoT.

The analysis of the data can show trends, issues, inefficiencies and preferences. The collection and analysis of data can be used to improve a system's efficiency, point the way to valuable resources, highlight population types and locations or even show that a piece of equipment is approaching failure. As humanity moves into space, our dependence on data will increase. So will the need to be able to share this data to persons across the solar system and with experts that are millions of miles away.

One of the key benefits of a solar system wide IoT system would be the ability to monitor and understand the various processes that are taking place in our solar system. For example, by monitoring the temperatures and compositions of different planets and moons, we could gain new insights into the geological processes that are taking place on these bodies. Additionally, by monitoring the movements of asteroids and other space debris, we could better understand the dynamics of the solar system and the risks posed by such objects.

Another potential benefit of a solar system wide IoT system would be the ability to study and monitor the effects of solar flares and other solar activity on the various bodies in our solar system. This information could be used to develop new technologies for protecting against the effects of such events, and could help us to better understand the dynamics of the sun and its impact on the rest of the solar system.

Proper IoT systems will allow experts to "be" in the field without leaving their office which will result in more efficient processes and the ability to design better vehicles, habitats and manufacturing processes. It will be used to find minerals, safe locations for landing sites and habitat sites. In short, IoT systems will let us conquer space and make it a home for humanity.

A. Problems

Several challenges arise when attempting to develop an Internet of Things (IoT) system based in the Solar System. The most significant challenge is distance. In his work The Hitchhiker's Guide to the Galaxy, Douglas Adams illustrated the immensity of space by having one of his characters say, "Space is big. Really big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist, but that's just peanuts to space." The distances involved are so colossal that conventional units of distance become meaningless. In response to this issue, scientists and engineers have devised a unit of measurement referred to as the light year, which is the distance that light travels in one year, or approximately 9.4607 × 1012 km (almost 6 trillion miles). This distance can be further broken down into a light second, which equals 299,792,458 meters (186,282 miles).These large distances affect communications in two ways, transit time and signal strength.

The chart below illustrates the transit times for radio waves, which travel at the speed of light, to travel between points in the Solar System.

Point to Point	Distance	Transit time
Earth-Moon	384,000 km	1.3 s (1.3 light seconds)
Earth-Mars	55 - 378 million km	3 - 21 minutes (180 – 1,260 light seconds)
Earth-Jupiter	590 - 970 million km	33 - 53 minutes (1,980 – 3,180 light seconds)
Earth-Pluto	~5800 million km	5 hours (18,000 light seconds)

Transit times pose a challenge for the sharing and accessibility of data across the Solar, particularly in maintaining an accurate time order sequence. When analyzing data, it is often necessary for it to be arranged in a chronological order to ensure its usefulness and comprehensibility. However, if data is gathered from various locations across the Solar System and subsequently transmitted to other locations, establishing a consistent time sequence can be problematic. To address this challenge, it is necessary for each collection point to possess a clock that is synchronized with all other clocks within the Solar System. This synchronization would enable data to be tagged with a time stamp, allowing for a meaningful comparison of data from distinct collection sites.

A straightforward example that highlights the utility of synchronized time stamps pertains to two measurement systems located far apart that experience similar failures in a relatively short time period. With synchronized time stamps, it would be possible to determine whether these failures were caused by a Solar System-wide event, such as a solar flare. By comparing the time of each failure with the travel time of the event, analysts could identify the order in which the systems were affected. For example, in the event of a solar flare, it would be evident that the system located closest to the sun failed first, followed by the more distant system as the shock wave passed. Without synchronized time stamps, it would be significantly more challenging to establish a link between the failures.

The time stamp is also critical for measurements of celestial, or other types of, events from distantly separate sites. Synced timestamps allow for easy alignment of timelines facilitating accurate comparison of the data.

NASA’s Deep Space Atomic Clock (DSAC) counts off the seconds with ticks that are about 50 times more uniform than the atomic clocks onboard GPS satellites. If these clocks prove to be reliable and robust then they could be used for syncing time across the solar system. Clock sync verification could be done through observation of a predefined celestial event such as pulse quasars or other easily detected timed events. Each collection point would utilize this type of clock to ensure data integrity at the final destination. As an aside note, these type of clocks could be used for extremely accurate navigation which would also be very useful for IoT networks.

Another problem that IoT encounters is signal strength. As electromagnetic wave propagates across space its intensity (signal strength) is reduced. The rate at which it is reduced is proportional to the inverse of the square of the distance. This effect applies to all electromagnetic waves and is independent of frequency. This causes a radio signal to be a quarter of its transmission strength at 2 miles.

The issue of low strength intensity in space communication is exacerbated by the noisy nature of the space environment. Unlike a quiet room, space is analogous to a bustling New York street, where a whisper would be easily drowned out by the surrounding cacophony, making it difficult for a listener in close proximity to the speaker to discern the message. This interference, known as electromagnetic interference (EMI), is a common experience for anyone who has used an analog communication device, such as a radio or TV, and is typically manifested in the form of "white noise".

Modern technology and algorithms are able to resolve low strength signals buried in noise. Which allows communication with probes at the edge of the Solar System. However, as distance increases the transmission rate must decrease reducing the volume of data that can be sent over time (bandwidth).

To address the challenges of distance, EMI, and signal strength, it is necessary to adopt a terrestrial system topology as a model for Solar System-wide IoT systems. To this end, mesh networks, cloud-based computing/storage, and multiple transmission modes can be utilized to overcome these challenges.

Mesh networks provide a means of establishing communication links between multiple nodes, enabling data to be transmitted over a more extended range than what is achievable with traditional point-to-point communication systems. Satellites, ground stations and mobile systems could be interconnected providing a robust system that is resistance to interference caused by EMI, individual unit loss or by a bad actor.

A terrestrial example would be of multiple edge computer data collection points interconnected by wifi and to a cellular tower. Normal operation would have each edge computer communicate to the cloud through a distant cellular tower. If an edge computer loses communication with the tower it can transmit the information through one of the other edge computers that still has connection. An extremely robust mesh network allows for multiple edge computers to pass on data until it reaches an edge computer that has communications with the cloud extending the reach of the system.

Another illustration of a mesh network can utilize communication satellites. Each satellite communicates directly to a ground station but if it loses contact with that station it could still send and receive information through other satellites that can still communicate to the target.

Expanding the network beyond consolidated operations or planetary bodies requires an expanded mesh network that utilizes relay stations, cloud computing hubs and multiple communication types / paths. In space, unlike in an atmosphere, all communication is by Line Of Sight (LOS). In an atmosphere certain frequencies can be bounced off an ionized layer and received half way around the globe. Shortwave radio works in this manner allowing people in different countries to communicate. The ability to reliably bounce signals in space does not exist, this requires each station in a communication to be able to “see each other”. Determining LOS is done by drawing a straight line between the communicating stations without intersecting another object.

Along with LOS the communicating station must also be close enough to overcome EMI and other interference. The distance between the stations is determined by the output power of the transmitter, the sensitivity of the receiver and the background noise. The working distance will vary dramatically based on what is transmitting, a small mobile system traveling through the solar system will likely have less power available for transmission then a fixed system, and what is receiving, again a small mobile system will likely have less capability to have large antennas and power for amplifiers then a fixed system. This leads to a philosophy of having multiple fixed systems (more power and space) that can communicate with each other and with smaller systems, essentially becoming a relay network that is also a large mesh network.

The large relay stations will need to be strategically placed throughout the solar system so that they can service multiple clients in separate locations. To justify the expense of these stations they must be able to service many different clients in many different areas. The location of the stations have to be selected to provide LOS to as many locations as possible as well as be sensitive enough to receive transmissions from small mobile systems.

Another way to increase the return on investment is by having the relay stations provide cloud services. Client use of the relay station will be necessitated by the reach of the client. Distance and transmission power may preclude the client from accessing other resources. In space distance equates to time, so if a client is attempting to access remote resources through the relay station, a considerable delay could be encountered as the data/request is sent from relay to relay and then finally the target. However if the resources, such as cloud computing, are located on the relay station then the delay is only as great as the distance to the relay station.

Part of the cloud computing service would be to provide database services. These services would allow the client to store and access data generated by the client. It would also, if designed correctly, allow the client to access data generated in a separate part of the solar system. If the relay stations are connected in a mesh network and all provide cloud computing services then data can be shared among all of the stations. As data is generated in one part of the solar system it would be sent across the mesh network until all of the relays have a copy of the data. In this way a client on earth could monitor and make adjustments to systems on the Moon, Mars and beyond without changing systems. The topology automatically provides data backup and security against loss.

B. Economic Benefits

The effect of IoT and cloud computing can be measured by examining the economic impact these system have had on terrestrial economies. When deploying an IoT or "smart network" enterprises typically save 4 to 5% of costs with minimal deployment which benefited global business in a productivity boost of $175 billion in 2018(1). In an article by Thierer and O'Sulivan they stated:

> "The cost savings and productivity gains generated through "smart" device monitoring and adaptation are projected to create $1.1 trillion to $2.5 trillion in value in the health care sector, $2.3 trillion to $11.6 trillion in global manufacturing, and $500 billion to $757 billion in municipal energy and service provision over the next decade. The total global impact of IoT technologies could generate anywhere from $2.7 trillion to $14.4 trillion in value by 2025."(2)

An integral part to any space based IoT system is the cloud computing component which has its own economic impact. In simple terms cloud computing allows users (business, explores, etc.) to rent hardware and software without the cost in resources for acquisition, installation and maintenance. All of the infrastructure is located at the vendor's facility and users access the system through a network. A user would only pay for the capacity that is used. The benefits to users of such a system include:

- Reduction of startup costs
- Rapid software updates and easy modification of software
- Cost sharing among consumers
- Variable computational capacity and increased efficiency
- Lower energy requirements for users

In the U.S. alone, cloud computing added approximately $214 billion in value-added to GDP in 2017 and approximately 2.15 million jobs.(3) Since 2002 the cloud economy has nearly tripled in size.

C. Obsolesces

Technology is always progressing making what was once state of the art obsolete. An enormous amount of resources will have to be used for the build out and maintenance of a solar system wide IoT system. New communication technology utilizing quantum physics could turn relay stations into obsolete resource sinks. Two methods could be utilized to mitigate such a problem. 1) Wait until the new technology matures or 2) build the relay stations so that they can be used for multiple purposes.

Waiting for the new communications technology has its own cost. The cost of missed opportunity could be greater than the cost to build and then abandon the system. As man progresses out into space the need for data will be great and immediate. The delay could not only squander precious resources but also result in the loss of life that could have been prevented.

Making the relay stations multiple purpose, and possibly reconfigurable for new customers, is the best path. It provides multiple routes for the return of investment and helps prevent the stations from becoming obsolete before their end of life. Multiple uses of the station equates to multiple revenue streams providing the best chance to profitability over the long term.

III.Solar System IoT Philosophy

The previously stated need and problems for a Solar System wide IoT system give rise to the following eight philosophical rules:

1. Data is paramount. The more data, especially quality data, increases accuracy of system models and improves decisions.
2. Quality data comparison and analysis requires time synced data. Each location has to have access to a clock that is in sync with all other clocks in the Solar System.
3. Data must be easily available to authorized users independent of location. Any authorized user should have access to data that is collected from anyplace in the solar system.
4. To ensure that users have access to data storage and analysis capabilities regardless of their location, it is necessary to establish relay servers with significant computing power and full cloud computing services available. This would enable users across the Solar System to quickly access the required capabilities, overcoming extended time delays associated with transmitting data across long distances.
5. Bandwidth determines data flow. Collection, dissemination and access of data will be limited by bandwidth. The greater the bandwidth the more data can be collected and analyzed. Number, size, transmission medium and location of relay stations will be determined by bandwidth. Locations with higher EMI or block to Line of Sight (LOS) will require a greater number of relay stations at a closer distance.
6. The IoT network must be have multiple data paths. All environments change over time, by natural and/or manmade events, stressing parts of the IoT system. Multiple data paths allow the flow of data around the affected area reducing loss of data and data corruption. This is equally important to both planetary locations and deep space locations.
7. Relay stations should be multi-use installations increasing short term profitability and act as a preventive to obsolescence.
8. He who controls the Data controls the fate of Mankind in space.

IV. Conclusion

As humanity expands into space, the need for the collection, transmission, storage, analysis and access of data becomes increasingly important requiring a unified Internet of Things. The space environment is imbued with many challenges to such a data system which must be overcome early in humanities expansion. A Solar System wide IoT system based on the basic philosophical rules stated in this paper provides the best path forward and ensures that the decision makers and leaders of the expansion have the data required for success.

References

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