NASA Challenge: Space Pioneering – Achieving Earth Independence

NASA ExoNet

This proposal describes a network designed to operate with either no or limited external communications. Transferring the bulk of its large data via MicroSD cards and smaller files and messages via a live data stream.

The Problem:

The astronauts on the Mission to Mars will be out of range of real-time network communications for most of the mission. Access to Internet like data will be delayed by many minutes and due to technical difficulties may be completely unavailable. Traditional methods of accessing Internet data and email do not adapt well to this extremely wide area network with massive latency.

The same problem exists when attempting to get all of the mission data logs back to Earth. Multiple systems, constantly logging data will quickly produce many gigabytes of data. Streaming these back to Earth will take up a significant amount of band-width.

The Proposed Solution:

A combination of data requests which queue up “live” data updates from Earth and shipments of massive databases on physical media carried on resupply flights can be amalgamated to produce a NASA ExoNet which provides astronauts with information that they do not yet realize they need.

As new shipments of data make the old storage media redundant, the old memory cards can be used to send massive amounts of mission data back with the returning astronauts.

Custom ExoNet applications will be created to handle e-mail, document management and even provide the astronauts with a gateway on to Twitter and other popular social media outlets which otherwise would time out with the long delay.

A final step has this technology being applied to Internet isolated locations on Earth, such as third-world villages.

NEVER UNDERESTIMATE THE BANDWIDTH OF A STATION WAGON FULL OF TAPES HURTLING DOWN THE HIGHWAY

Tanenbaum, Andrew S. (1989)

Introduction

Traditional computer networks are designed to wait a short amount of time before receiving information back. As Internet users we are conditioned to wait only a few seconds before accessing a web site. If we try to apply conventional network design to any computer network which leaves Earth's immediate vicinity it will fail on both of these counts.

When Earth and Mars are at their closest, radio/laser signals still take approximately 4 minutes to make the trip one way. As the planets separate (Mars takes approximately twice as long as Earth to Orbit the Sun) this distance starts to increase up to approximately 12 minutes. At this stage the Sun might be between the two planets, requiring any signal to take an even longer detour around. But these delays cause significant problems even earlier in the mission than that. If it takes Astronauts 6 months to travel to Mars, within the first week they will already be approaching a 20 second round trip delay on all communications.

The proposed NASA ExoNet will combine a number of technologies to provide the astronauts with the data they need to survive and thrive independent of Earths Internet. Some if it will involve access to existing data (reference material, instructional videos), other aspects will cover collaboration tools, such as sharing documents and a new ExoNet mail system.

The ExoNet is expandable to encompass multiple planetary missions. It will start off with Earth, The Moon and Mars but can be expanded to other worlds such as Venus and Titan if required.

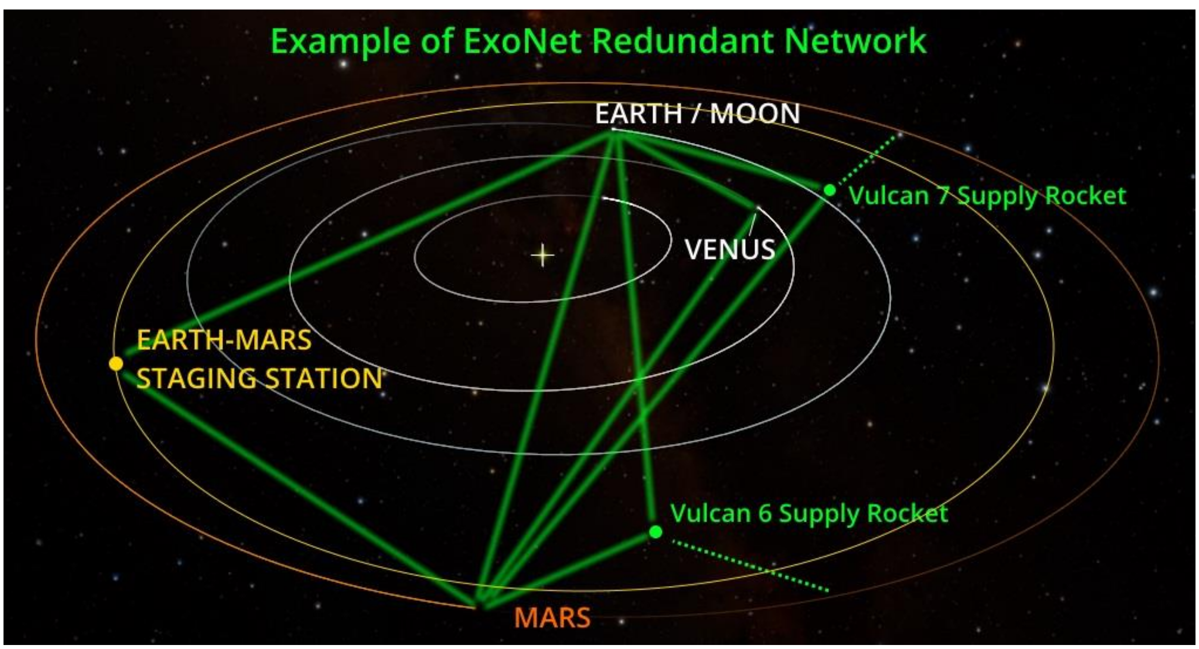
Contents

Assumptions

1. There will be regular (every 6 months?) supply missions from Earth to Mars.
2. There will be some sort of streaming live data link (either existing radio waves or the Deep Space Optical Communications project), which will of course be subjected to a multi-minute delay.

Live Links and Cargo Runs

Data will be transmitted between the ExoNet nodes via a combination of live data streams (radio or laser based) and physical media on cargo/crew transports. As can be seen from the diagram below, communicating between the planets, orbiting space stations and supply ships would quickly produce a network with a reasonable degree of redundancy. So even if one of the links failed, the affected node would not be out of contact with the rest of the ExoNet.



An algorithm on each site would calculate the shortest path for any message (based upon the current orbit position of each other site), but data would also be able to use alternative routes in event of a problem.

Reference files

Much like the early World Wide Web, the shared ExoNet data will be far more academically biased and less about cats with poor spelling. The data on the ExoNet will be controlled by NASA to make the most of the bandwidth, to ensure the veracity of the information and to protect against viruses or Trojan horses.

While it is anticipated that astronauts will be highly trained in many fields, having access to either new educational material or simply reference material to refresh ones memory could become critical to mission success. Take for example a situation where a crew member falls ill with acute appendicitis. A crew member qualified as a surgeon may well have been trained in the procedure, but that training may have been many months or years previously. It would be useful if they had a local copy of an instructional video to refresh their memory before operating on their patient, especially given the distance to the nearest hospital if things start to go badly wrong.

Courses and lectures on the core science subjects present themselves as potentially very useful for the mission. I can see obvious applications for training in Surgery, Chemistry, Biology, Physics, Astronomy, Mathematics, Computer Programming, Agriculture, Electronics and Geology. I am sure there many more.

The good news is that much of this data is already available online in the form of video lectures from the likes of MIT. I am sure that they would happily partner with NASA to provide the source videos for the database.

Other types of instructional video (such as surgery or specific NASA equipment repairs) might have to be produced by NASA, but the cost of this would be offset by the knowledge that these videos can be used in all future astronaut and technician training.

Having covered the basics for the mission, the next use of data is intended to fulfill the astronauts' psychological wellbeing, whether it's through entertainment or personal development. It is likely that all mission crew members will be travelling for many months. By definition, astronauts tend to be highly driven individuals, and I doubt they will be content to sit around doing nothing for the entire flight. On the International Space Station, astronauts have experiments to occupy their day. However there is no advantage (that I can think of) to doing experiments in deep space rather than orbit. As such a Mars in-flight experiment is just extra weight that has to be shipped all of the way to Mars and back. Therefore keeping the astronauts occupied via entertainment and personal development becomes critical to a successful mission. Low bandwidth items such as books and magazines could be streamed via the live data stream, but a large selection of periodicals, movies, TV shows and games can be included in the ships data banks.

Mars University

If part of the ExoNet program is to provide educational resources to astronauts on their flight and on planet (including when they might otherwise be out of contact with Earth), it makes sense to also introduce an automated testing process for each educational module which randomly generates a quiz based on the course information and scores the astronaut appropriately.

Our driving force behind this off-planet education system is partly to keep the astronauts engaged during long periods of down time and partly to enhance their knowledge and therefore improve the mission's chances for success.

If we develop the training course and the automated test procedures, then it won't really cost much more money to roll this system out to all NASA employees. This is where we would see massive dividends on the money invested. Providing employees with structured training courses on subjects they are interested in will raise the over-all knowledge level of NASA as an organization, which will in turn contribute to the safety and success of all future missions.

Having spent the initial investment on the training for the astronauts, and then having rolled it out to NASA employees, the third step would be to make the non-classified courses available to all people from around the world. Let them register and start a course on astrophysics, or chemical engineering or agricultural science.

As the only organization with an active presence on Mars you could legitimately issue certificates from Mars and make the whole educational tree part of “Mars University”. Of course, this is light-hearted and not by any means intended to be taken too seriously, however when you look at the reasons people strive for an education, it is often just the opportunity to learn, not to say they have a degree from Yale.

Mars University, as Earths first off-world educational institute would provide courses to quench this thirst, and they would in their own rights become a way for people without access to tertiary education to learn and grade their knowledge.

So, a kid from Mozambique might go through the whole course in Agricultural Science with the sole intention of helping his family farm. In turn he can help others do the same course. This course, originally intended to help the scientists on Mars grow food is also contributing greatly to human health and well-being here on Earth.

A teenager in Mexico is using the Mars University program to teach herself Robotics. The fact that she has completed this course might be enough to actually get her employed in the field, or at least gives her a better chance of getting accepted into a University Science Course.

Using the money invested in astronaut training to further enhance the knowledge/skillset of the entire human race is an excellent return on investment.

And then of course, there's the fun of having Mars University Alumni and sweatshirts etc. If you want people to learn, make it fun. Nobody is seriously going to be misled by a Mars University Logo Sweatshirt, but it might pique their interest enough to ask about the institute, and through that spread the word of knowledge.

Of course, if you do go ahead with Mars University I would recommend that you avoid using the slogan from Futurama's Mars University[1].

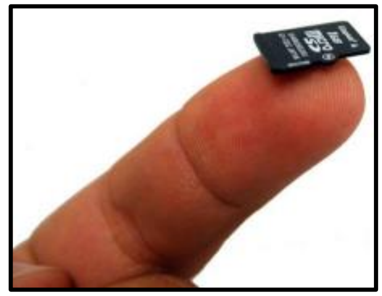
Storing the data

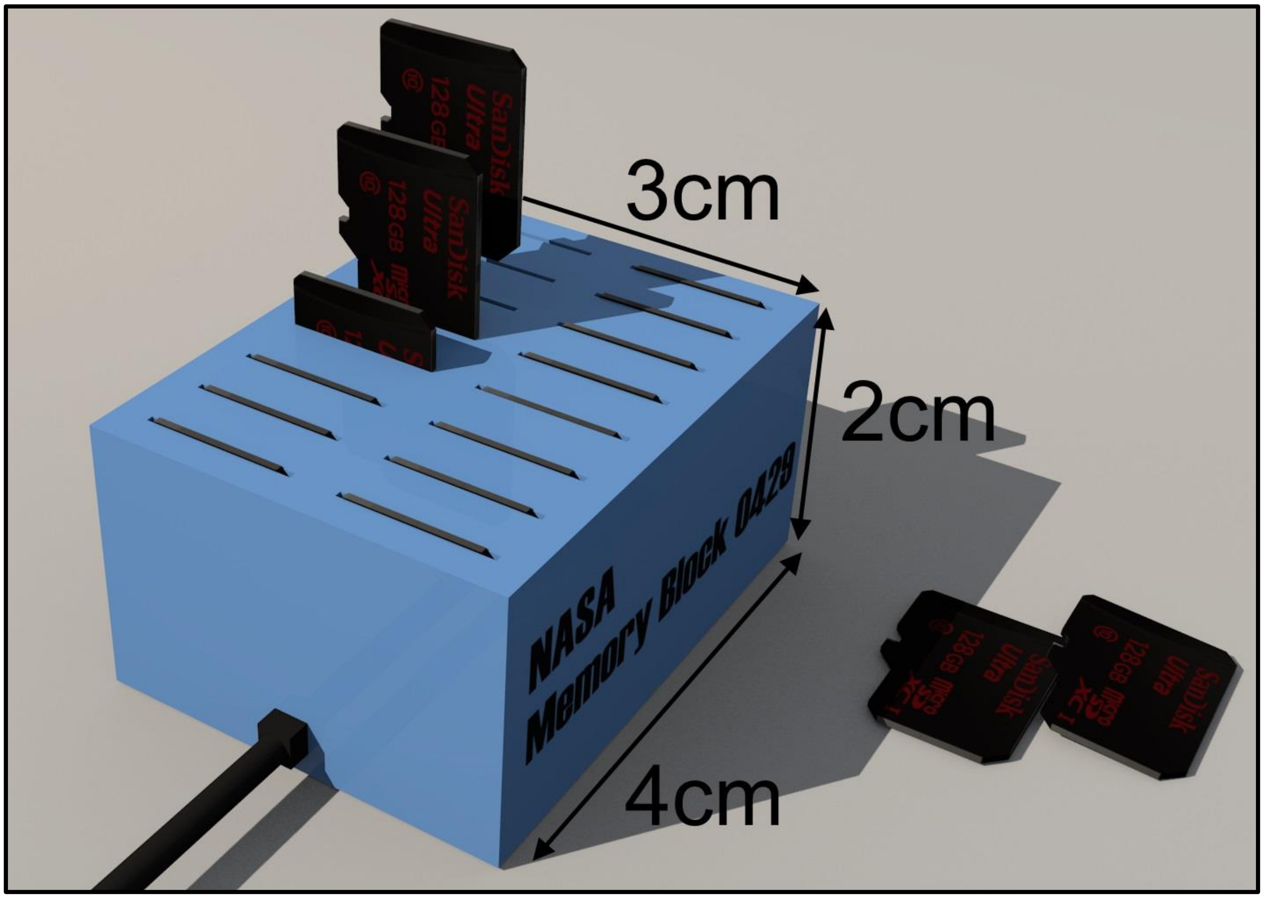
The most obvious form of data storage for the mission is the hard drive, but they are actually quite heavy and multiple drives would be required to provide reasonable redundancy over a multi-year mission.

A more suitable medium is the MicroSD memory cards often used in phones and cameras. These are significantly lighter and more reliable (having no moving parts). The down side is that they are so small they are difficult to physically handle and they are significantly slower than hard drives (though fast enough for our purposes).

[1] Knowledge brings fear.

Currently the MicroSDXC standard is available in capacities up to 128 Gigabytes, however future cards are expected to reach 2 Terabytes. The picture to the right shows just how small each card is (11mm x 15mm).





An interface box which houses 16 of these cards would be very light and very compact (as shown in the image above), yet have a capacity of 2 Terabytes (16 x 128GB), rising to 16 Terabytes as the technology improves. This would allow astronauts and re-supply missions to transport significant amounts of data to and from Mars.

Delivery to destination

Once each block of MicroSDXC cards is delivered to its final destination it can be plugged into the network and starts to index itself based on the following rules.

- If this is a newer revision of a file, then delete the old revisions.
- If two or more copies of this file already exist on the network, then delete the new copy (so that there are only two copies of the file left).
- If this is the only copy of the file on the network, then make a backup copy on one of the other MicroSDXC cards.

By following these rules we should end up with two copies of the latest revision of each file available on the local network[2]. Deleted files free up space on the MicroSDXC cards. If enough files get deleted, then the few remaining files on a card can be moved off to another card, leaving an empty card. This can then be used to store the files from the mission that are due to be sent back to Earth with the next returning crew.

Maintaining an Index of the Data

Each file in the system has a “home server”. This defines the server computer that maintains the revision control, distribution and locks on any file. Typically a file created on Mars will have the Mars Server as its home server and a file created on Earth will have the Earth Server as its home server, however there is nothing to stop the home server of a file being changed and moving control of the file to another location.

This system allows us to easily expand the ExoNet out to orbital stations and other planets.

[2] For some files we may want to retain older revisions. This is covered later in this document.

For example: The database on Earth maintains an index of where every Earth based file is, and which copies are still in flight (on a crew or re-supply ship). Each file has a list of destinations, and it is constantly trying to get to each of these destinations, hitching a ride on every ship heading there until it is registered as having been received. For example:

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Video Procedure to Clean Greenhouse Filters Revision 5
Destination: Mars Base
Current Locations: Earth Database, Vulcan Supply Rocket 7 (6 months from
Mars), Vulcan Supply Rocket 6 (3 months from Mars)
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Once Vulcan Supply Rocket 6 reaches Mars, then the file will be noted as having arrived and as now being available to the Mars crew members. It will not be included on future supply rockets, and when supply rocket 7 arrives it will be deleted from supply rocket 7's database.

The Index of available Earth files is broadcast daily from Earth to all off world ships/stations/bases, along with which off-world files they have received. In turn each ExoNet home server will also broadcast which files they have available and which they have received.

For the above example, if an astronaut on Mars tries to call up the procedure to clean the greenhouse filters, they will see that they have revision 4 of the procedure on site, but that revision 5 is on its way. They will be given the option of viewing revision 4, or having revision 5 transmitted to them via the live stream (using valuable bandwidth).

If they opt to stream revision 5, then the database will know that a copy has made it to Mars and the copies on the supply rockets will be deleted when they arrive.

The idea here is that the crew always have the option of streaming files live (using valuable band-width), but for many files which are not required urgently (updates to instructional videos etc.) the background shuttling around of files will keep their local databases fairly up to date.

Each file therefore has a list of destinations that it is trying to spread to, and a record as to if it has been successful for each destination. This gives NASA a simple automated system for disseminating files to all of their off world locations, that automatically tracks and collates the files.

Example 1

A NASA tech creates a video file showing how to troubleshoot the motor on the standard astronaut treadmill. They upload the file to the NASA database and set that it needs to be sent to the following locations (Mars Orbital Station, Mars Base 1, Moon Orbital Station, Moon Base 1, Moon Base 2 and the International Space Station). That's all they need to do, the system will build databases to be sent on the various supply rockets and keep sending them until the files has been received at each destination. If an astronaut needs the procedure before then, they can opt to get it transmitted via the live data stream.

Example 2

Its Christmas time and an astronaut's family want to send him a book. NASA uploads the file to the database and marks it as "To be delivered immediately" to Mars Base 1. The system will not try and send it via the MicroSDXC cards, but will schedule it for transmission on the radio link to Mars. The book will then appear on the astronaut's database of files.

Example 3

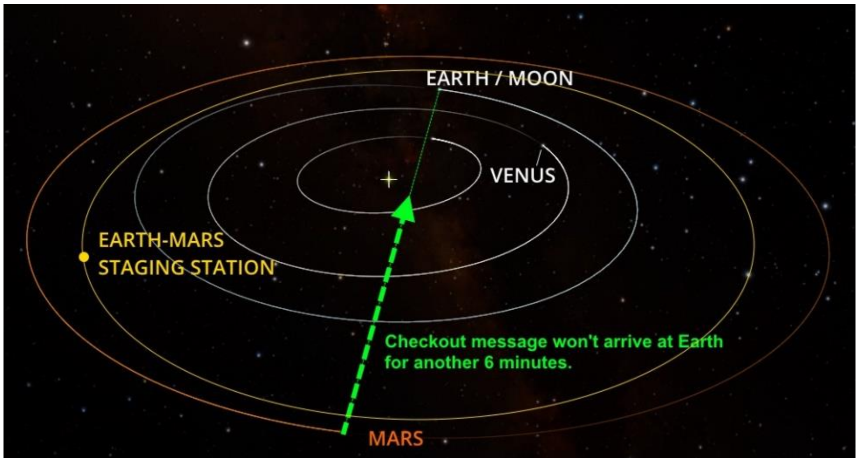
The systems on Mars send back regular log updates of all the site data recorded at 10 seconds intervals via the live data link. Mission control would like to see the 100 µsecond log from the survey robots from the last 6 months. If it is urgent then it can be transmitted back to Earth on the live data stream, if not then it will be copied to one of the MicroSDXC cards scheduled to go back to Earth with the crew. Every time there is a vessel going back to Earth, this file will be copied to the returning data cards until it is recorded as having been delivered safely. It should be noted that in the same way that a Mars astronaut does not need help from Earth to pull an Earth based file, these files, although they have Mars as the home server can be pulled directly by the NASA team on Earth. It does not need interaction from the crew on-site. This allows researchers to access detailed data without disrupting the astronauts.

Collaborating on Documents

The previous methods work well for library files; that is documents which do not change regularly and may not be required for a long time (if ever). However, some documents are updated far more regularly. The NASA ExoNet system handles this by allowing documents to have an “owner”. The owner can make updates to the document at any time and once published this new document will become available to all recipients. An example of this would be an astronaut’s daily exercise diary. The astronaut updates it each day and clicks “publish” when she is done. This sends a copy via the live data stream back to Earth for the flight physicians to review. As the owner of the document, she does not need to worry about checking it out for changes, as no one else has write access to it.

In the same way, files originating from Earth will have mission control staff members set as the owner, allowing mission control to make regular updates and push them out to the off world locations, but they will not be editable by the off-world crew members.

If there is no owner set, then anyone can check the document out to edit it. With an Earth based Internet system this would be straightforward, but with the time delay this becomes a bit more complex. The system operates an optimistic locking mechanism. If a crew member on Mars checks out an Earth document (home server set to Earth) for editing, then the system will allow him to open it and start editing, but will send a request to the database on Earth for the checkout (on the live data stream). If no one else tries to edit the document in the time it takes for the signal to reach Earth, then all is good. If however, someone on Earth (or the Moon/ISS for that matter) tried to check out the same document before the signal arrived, they too would be allowed to start editing. When the conflicting checkout requests are compared, the newest one is rejected and a message sent back to that astronaut informing them that "Sorry, but the document has already been checked out by crew member Sarah Jane Smith".



This may cause a minor inconvenience to the second editor on the odd occasion that it happens, but keeps the system simple and doesn't delay the off-world workers (waiting for check-out approval).

Of course, if the Mars based crew member was checking out a document which is registered as having Mars as the home server, then the check-out would be instant.

Such a system would facilitate astronauts collaborating across many off-world sites, so crew members who are midflight to Mars could already be helping their colleagues on the planet with their work.

This collaborative documentation system would be designed so that it is easy for crew members to create new projects in a structured hierarchy and to invite other team members (on Earth or off-world) to participate. Such projects do not necessarily need to be work related and like-minded crew members may spend their down time designing a new board game or working on a novel together.

In short, collaborative files (word documents, spreadsheets, computer programs) can be shared between all Earth based and off-world sites.

Sharing Folders

Sometimes rather than collaborating on a single document, it makes more sense to collaborate on a whole folder of files and sub-folders. A good example of this might be a set of engineering drawings, where each drawing is held in a separate file or a computer program where the source code is split across multiple files. ExoNet will identify which files/folders have changed and synchronize the changes between the team members.

Revision control allows team members to roll back to previous versions if required. Again, there are many applications which already allow this sort of collaboration on Earth (such as Microsoft Visual Studio), however they would all time-out and fail with the long ping time to off-world team members.

Private Documents

Even personal documents should be held on the NASA ExoNet even if they are not intended to be shared with others. These documents gain the advantage (shared by all ExoNet documents) of automatic backup to redundant media, encryption and version control.

Reference Number

Every file within the system has a unique reference number that is used to identify it. Therefore in a conversation a staff member might say “Could you have Dr. Jones look at the soil acidity readings in document #99327?” and Dr. Jones simply needs to type 99327 in to their computer and they will retrieve the latest revision of the correct document (assuming they have security clearance for it).

Revision Number

Every document has a revision number. The revision numbers that end in .0 are reviewed and published. For example, a document may have revision number 0.1, 0.2, 0.3, 1.0, 1.1, 1.2, 1.3, 1.4, 2.0, 2.1

In the above example, people working on the document would automatically open revision 2.1, but could retrieve any of the previous revisions if required. When they are happy that a version is ready to publish the revision number will be set to the next whole number (in this case 3.0). Users who can view the document but aren't working on it, automatically retrieve the latest published version (and cannot see the working revisions). So, an astronaut looking for a copy of this document would get revision 2.0.

Some files can be flagged so that previous revisions are not kept. They will still be under revision control, however older revisions of the files might be deleted by the servers to save space. This is particularly important for off-world servers where space might be at a premium. So, if there is a new revision of the Video of the Appendicitis Operation Review, then the old file will be deleted to save space.

Recap

To recap, each document has:

A Home Server: This is the server that records the master record (such as who has it checked out for editing). Typical values are Earth, Mars, Moon etc.

Owner: This is an optional field. If set to a staff member, then only they can edit it (although others can add comments to it – see later). If it is set to no-one, then anyone with write access to it can edit it.

Project: Documents must belong to a project, even if it is a private project of a crew-member. This is to help keep everything organized.

Unique Id: Used to make identification and retrieval of the correct document easy.

Revision Number: Allows multiple revisions of documents. Revision numbers ending in .0 are reviewed and published versions of the document.

NASA ExoNet Mail

While there is no real reason we could not implement normal e-mail over the ExoNet, it would be far more efficient to implement a new type of mail system designed to reduce bandwidth usage of the live data stream.

Attachments

The first step would be that attachments would become references to existing files within the ExoNet. Therefore if someone wants to send a file to an astronaut, it has to be loaded into the ExoNet as a file and undergo all of the controls that are in place for it. For example: Doctor Smith sends a Mars astronaut a video file which demonstrates the appendicitis procedure to be carried out. If that video file has already made it to Mars, then the reference link will open the local (Mars) version of the file, rather than have it re-transmitted across the live data stream.

Because the attachment references the Unique Id of a file, when it gets opened the system will retrieve the latest revision of the file. So if a team member goes back through their emails and opens a document, and it has been updated since then, they will get the updated version. Of course, as with all version controlled files if they wish they can go back and retrieve older revisions if required.

Attachment Tasks

When adding an attachment to an ExoNet message, the receiver can be assigned a task that they are expected to carry out, such as review this document. Clicking on the link will open the document (in Microsoft Word for example) ready for comments to be added.

Once the assigned task has been completed, the user marks the task as done (within the email) to say that they have reviewed and logged their comments. These comments are automatically amalgamated with all other users' comments so that the original document creator can view them[3].The original author can look at the email they sent and see a real-time list of who has completed the review.

Meta-Data Forms

Sometimes it is a requirement just to gather and file form data. To this end the NASA ExoNet has the concept of meta-data forms. This is simply user created fields that can either be linked to ExoNet files or exist as entities in their own right.

For example, I might create a type of form to manually record the astronauts sleep quality each morning. The fields I want the astronaut to fill in are "Astronaut Name", "Time to bed", "Time of Wake Up", "How well rested are you (0 to 10)", "What kept you awake" and so forth.

The astronaut can create a new instance of this form whenever they want and fill in the fields which will be transmitted back through the ExoNet to the project team that is carrying out the research.

[3] We do not need to worry about file locking here as comments in Microsoft Word/Excel etc. can all be easily amalgamated into a single document.

This may seem like a normal database entry, but the point here is that the database holds a definition for each form (hence the meta-data), not individual fields. In other words, without changing the structure of the database, or indeed without even knowing anything about the database, I can create any form I want, with any amount of fields and this data will be gathered.

If required, these meta-data forms can also be linked to files, providing another avenue for searching and retrieving data. If a crew member notices there is a problem with the daily gas-chromatograph logs, they could fill out a bug report form for the gas chromatograph team, attach the log file and save to form. This form will go to the team members who can start working on the problem.

General Enhancements

ExoNet Mail will also have some general enhancements that can't be done with normal email. For starters all e-mail and files transferred via ExoNet are encrypted and compressed. They are also permanently stored on the server, even when "deleted". This last part is important, this isn't some shady business trying to circumvent legal oversight. As a very respected government organization, having a fully auditable document trail is critical to the integrity of the NASA mission. A permanent tamper proof archive of all communications is an important element to maintaining this trust.

Other enhancements such as the ability to recall and amend sent messages, to see who has read the message and to link all messages together in one conversation tree all help to improve the flow of knowledge.

In ExoNet Mail all mail messages must be linked to a project (even if it is just a private personal project). This has two big advantages. It means a message cannot be sent to someone who is not part of the project (for security/privacy reasons) and it also means that the messages can automatically be filed under the appropriate project. So if someone is retrieving all of the documents for a specific project, they will also see all of the messages linked to it.

A major advantage over current internet email is that the ExoNet mail enforces the identification of each user. This is first and foremost a secure communications network. All participants are provided a secure log on and varying levels of security access to data. This means no spoofed email addresses, no spam and no messages forwarded to users not authorized to view that projects files.

As you can see from the features, ExoNet Mail is aimed at a far more serious level than e-mail. Users should be aware that its contents are archived forever and that anyone may have access to the mail messages in the future (if they are assigned on to a project). This is a corporate communication system designed to document the ongoing projects and decisions. Given the significance of the Mission to Mars, the contents of these e-mails will undoubtedly be of massive historical significance in the future and should be preserved.

Encryption

All files and messages passed through the ExoNet system are encrypted. Each home server has its own encryption key, which is re-generated each month. The new encryption key is then sent to the other home servers (encrypted using the previous encryption key). This means that even if a 3^{rd}-party does intercept some of the data and decrypts it, that key will become useless after one month.

Dates and Calendar

Time management on Earth or near Earth orbit is easily handled. Most computer systems use Greenwich Mean Time and then offset the user's timezone. This isn't going to work for off-world systems.

Proposal for NASA ExoNet

For deep space systems (such as transport to another planet) the crew can stay on Earth time without any problems, however when we get to Mars we will need a system for Mars Local Time as well.

It is out with the scope of this document to come up with the definition for Mars Local Time, however we will provide a simple example so that we can examine possible methods of handling it.

We need the Mars based astronauts to be operating on Mars Local time as we will want them to schedule most of their outdoor work in the hours of daylight, and I suspect that the rising/setting sun will help to regulate their circadian rhythm.

A Martian day is 24 hours 40 minutes[4]. So the simplest way of handling this would be to have a clock that continues to Earth Seconds, Minutes and Hours and just have it go to 24:40:00 instead of 24:00:00.

This of course means that Earth and Mars will move out of step by 40 minutes each day, re-synchronizing every 36 days. This is probably the most important distinction, as at times mid-day for the Earth based team members will be mid-night for the Mars based members. All dates within the ExoNet can be shown in multiple time settings. Therefore, data gathered at 10:43:22 GMT might also be shown as being gathered at 22:03:22 Mars time. When scheduling work it will be easy for the planners to see what a reasonable time is for the off-world crew members, and when they can expect to see the results back in Earth time.

A Martian year is 668.6 Martian days (or 686.98 Earth days). If we split the Martian Year into 12 months of 55 days each (with some at 56 to round out the last 8 days) we could easily identify if Mars is currently in its winter or summer state.

[4] It's actually 24 hours 39 minutes 35.24 seconds, but we are rounding to 24:40:00 to explain the general principle.

Regardless of the system chosen, the point is that the ExoNet would store all of its date information in GMT format and translate that into Mars Local Date-Time as required. This system can easily be extended for other off-world mission such as Venus local time.

Gateway to other systems

Chris Hadfield's Twitter account proved the value of social media in raising NASA's profile. By the time the Mars mission comes around, who knows what Internet based systems there will be for communicating, but one things for sure, they are unlikely to be designed to accommodate a ping time in excess of 8 minutes. Therefore the ExoNet can be used to provide astronauts with a Gateway on to the Terrestrial Social Media sites without requiring an Earth based team member to manually update their messages.

Developing and Testing the System

As a computer programmer I can say that there is nothing in this proposal which couldn't be achieved using today's technology. A test site could easily be assembled on Earth, with artificial delays between the stations simulated by deliberately delaying the delivery of the messages back and forth across the network. Hand transferred data blocks would simulate the departure and arrival of cargo/crew transport vessels.

When NASA comes to do an Earth based simulation of the trip, this sort of network could easily be integrated into the simulation (using the message delaying methods described earlier).

The final test would be to implement this network out to the International Space Station or even a moon base.

Summary

I hope I have shown that a combination of live data and cargo based mass-storage can be automated to seamlessly move data between Earth and Off-World stations/bases. Building upon this network with document control and secure mail enable greater productivity from off-world team members. This system is very viable using today's technology and for very little cost will free up large amounts of bandwidth used to transmit between off-world sites.

The bulk of the cost of this proposal would be in providing the on-going high level education for the participating astronauts and ground crew, but as mentioned this could be leveraged to provide a free worldwide educational system on Earth that can be used to provide tertiary level courses to people who would otherwise be unable to afford/access this knowledge. The technology developed for amalgamating and physically transporting the data to Mars, is well suited to providing educational videos and knowledge to third-world countries which do not have reliable Internet connections.

Thank you for taking the time to read this proposal.