Information Technology Support for Mars Research Missions

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Abstract

This paper describes an infrastructure that will support the work of a small group of researchers and explorers on Mars. The infrastructure and tools suggested seek to minimise the impact of the extremely hostile environment and the long highly variable delays in communication on the explorers.

The difficulties and unique features of the Mars mission are discussed and four components of the proposed infrastructure are described.

These components include a tool and infrastructure to search for information, a tool to support the recording of experiments/exploration, a tool to manage a changing mission plan and a tool to manage large volumes of electronic correspondence.

1 Introduction

This paper discusses some suggestions for a set of tools to support explorers and researchers located on Mars reporting to and cooperating with Earth bound researchers. To accomplish this the paper will describe an information infrastructure and a set of tools to be used by the mission.

The infrastructure discussed is independent of the underlying Internet infrastructure. The information infrastructure proposed can be implemented equally well on both IPv6 and IPv4. In particular, we do not seek to reproduce the work on extending IPv6 to operate over interplanetary distances[11, 5].

To establish the difficulties associated with the problem space the paper initially addresses the key and unique features of the Mars mission. The environment's physical, social and organisational attributes that impinge upon the information infrastructure will be discussed (section 3). Subsequently, four components of the proposed infrastructure are described which cover a wide range of potential exploration, research and mission activities.

The four components include a tool and infrastructure to search for information (section 4), a tool to support the recording of experiments/exploration (section 5), a tool to manage a changing mission plan (section 6) and a tool to manage large volumes of electronic correspondence (section 7).

Some research questions surrounding the components and potential opportunities to apply the technologies to terrestrial problems are also identified (section 8).

2 Objectives, Constraints and Goals

The objective of this project is to explore technologies and architectures that may be used in support of a manned mission to Mars. These technologies will be explored within an Earth analog environment where the challenges of the Martian environment will be simulated. Current available technologies, regulatory restrictions and budgets will constrain the design of the analog devices and simulation. Differences between the Earth and the Mars environment will only be considered where the resulting behaviour specifically alters the outcome of the experiment.

In the long term we will optimise the design to:

- Include redundancy in the infrastructure for emergency situations.
- Maximise the utilisation of resources under normal operating conditions.
- Reduce the size of the spare parts inventory - fewer types of spare parts reduces the risk of not having sufficient supplies of a key component, can reduce the amount of mass that needs to be transported and simplifies repair procedures.
- Use commercial components where suitable - this may reduces costs and lead times, and allows more familiar devices to be used by the explorers.

A key component of our philosophy is to simplify tasks and provide automation of routine activities to reduce the work load on explorers in an extremely harsh environment. We will also endeavour to remove, where possible, the work disrupting effect imposed by time delays.

In the short term we will attempt to construct a system that can be used by the Mars analog stations and develop projects to evaluate some of the operational difficulties that are expected to be encounter in the actual mission.

3 Physical Attributes

This section discusses relevant physical properties of Mars and their anticipated impact on the communication requirements of the Mars mission. Our intent is to develop a communications model to account for the limitations imposed by distance, environment and other factors related to a manned mission to Mars. This model is intended for testing on Earth-based missions in the near future, such as the Mars Analogue Research Stations developed by The Mars Society[23].

This section is in two parts, the first covering the effects of distance and the second investigates some of the potential influences of the Martian environment. The environmental factors will be considered under the following headings.

- Power Requirements
- Communications
- Radiation
- Navigation
- Weather
- Habitation
- Environmental Hazards

3.1 The Tyranny of Distance

Astronomical Data	Units	Mars	Earth
Average Distance from the Sun	*million km*	228	150
Perihelion	*million km*	206.62	147.09
Aphelion	*million km*	249.23	152.10
Closest approach to Earth	*million km*	54.5	
One way trip (light)	$hrs : min : sec$	0 : 2 : 2	
Furthest distance from Earth	*million km*	401.3	
One way trip (light)	$hrs : min : sec$	0 : 22 : 19	
Polar Radius	km	3375	6356.8
Equatorial Radius	km	3397	6378.1
Mass	$10^{24} kg$	0.64185	5.9736
Density	kg/m^3	3933	5515
Gravity	m/s^2	3.69	9.78
Length of Year	Earth days	(687)	365.25
	Mars days	668	(355.1)
Length of Day	hrs:min	24:37	23:56

Table 1: Mars - Physical Data Comparison with Earth 1. Astronomical Data[13][17]

The single most significant factor in the Martian communication model is physical distance. At closest approach, when Mars is in opposition (from Mars' point of view, when the Earth is in conjunction with the sun), Mars is 54,500,000 km away. This represents a transmission delay for a radio signal of approximately 122 seconds. A round trip will take 244 seconds. When Mars is at it's furthest distance from Earth, a radio signal will take over 22 minutes just to make a one way trip. The time delay could be larger, depending upon the number and placement of any relay satellites. Communication standards used for Earth-bound communication networks are not appropriate for interplanetary communication. An Interplanetary Internet is an active research project at NASA and solutions to the technical communications issues, such as minimising data loss and re-transmission, will not be discussed here[11, 5].

3.2 The Effect of the Environment

There are only a few points on which Earth and Mars are similar. A visitor to Mars will not notice a difference in the length of the day compared to Earth, unless they are talking to Earth on a regular basis. The slight mis-match (approx 41 minutes) between the Earth's day and Mar's day means that the working day on Mars will gradually get out of synchronisation with the Earth working day. This will cycle approximately every 35 days. A gradual change would be noted in the communications between individuals across the Earth - Mars gap, while the Earth and Mars are sufficiently close that something approaching a conversation is possible. When the Earth and Mars are sufficiently far apart that a normal conversation is unlikely to be possible, and this is likely for the majority of the journey, or where communication is between individuals on Mars and a team of people on Earth, who can act as proxy for each other, this effect will be much less pronounced.

Mostly, however, the visitor to Mars will be confronted with significant differences compared to Earth. The gravitational force is much lower, around one third that of Earth and the air is much thinner, approximately one fiftieth that of Earth and composed mostly of CO_2. Even if you could breath the air, it would be very difficult to communicate by voice because the thin atmosphere makes sound travel very poorly. This means that all communications must occur using other methods and this is most likely to be radio based communications between pressurised containers (habitat, suits, transport, orbital station, etc.)

There are several factors that will impact on the operation of communications equipment.

3.2.1 Power Requirements:

The temperature on Mars is much lower than on Earth. This has consequences for battery size and power (batteries will be less efficient). Solar radiation is approximately half the strength it is on the Earth, with direct consequences for solar panel efficiency.

3.2.2 Communications:

Mars does not have a magnetic field nor an ionosphere. Consequently, radio communication is approximately limited to line of sight. In addition, the horizon will be noticeably closer as the radius of curvature of Mars is 53% that of Earth. To a first approximation, the terrain will be rougher, with deeper valleys and more rugged mountains. However, even on a flat plain, the line-of-sight communication distance will be about half that on Earth.

3.2.3 Radiation:

While the level of incident solar radiation is lower on Mars than on Earth, the same lack of Ionosphere and Magnetic Field (and hence, no equivalent to the Van Allen Belt) that limits radio communication may allow the full range of the solar storms and cosmic radiation[7] to impact on equipment. It is speculated

Planetary Data	Units	Mars	Earth
Length of Day	hrs:min	24:37	23:56
Atmospheric Composition			
Ar	%	1.6	0.934
CO_2	%	95.32	0.035
CO	%	0.08	–
H_2O	%	0.021	1
N_2	%	2.7	78.084
NO	ppm	100	–
Ne	ppm	2.5	18.18
O_2	%	0.13	20.964
Atmospheric Pressure	kPa	0.61	101.325
Atmospheric Density	kg/m^3	0.020	1.217
Average Temperatures	^oC (^oK)	-65 (210)	15 (288)
Diurnal Temperature Range	^oC (^oK)	-89 *to* -31 (184 *to* 242)	10 *to* 20 (283 *to* 293)
Average Surface Magnetic Field Strength [16]	nT	$0-1,500$	$3,000$
Incident Solar Flux @ equator	W/m^2	589.2	1367.6
Background Radiation[4][3]	$mSv/year$	4[1]	$1.5-3.5$
Mean Wind Speed	m/s	$2-10$	$0-100$
Peak Wind Speed	m/s	$15-30$	100
Topographical variation	km	30	20

Table 2: Mars - Physical Data Comparison with Earth 2. Planetary Data[13][17]

that this may affect radio communications by interference or damage circuitry by cosmic radiation. It is worth considering that communication equipment may have to be hardened against cosmic/solar radiation.

To complicate matters, there is some evidence that Mars once did have a magnetic field, remnants of which still exist, frozen into the crust[18]. The remnant magnetic field in these places is of similar strength to that on earth and reached 100's of km above the surface.

> Indeed, it appears that Mars' magnetic umbrellas act like miniature magneto-spheres. They ward off the solar wind in their vicinity and harbour pockets of gas ionised by solar UV radiation that would otherwise be blown away.[18]

This suggests that in these areas, radio wave reflection may be possible, depending upon the solar weather. This may or may not be advantageous, protecting from cosmic radiation and allowing limited radio wave reflection locally, but the constancy and potential for radio interference may need to be evaluated.

3.2.4 Navigation:

Mars presents some peculiar difficulties for navigation. The lack of magnetic field implies other methods are required to determine direction.

A range of existing techniques, including radio-based techniques (satellite GPS, pseudolites (ground-based pseudo-satellite) GPS[14] [19], radio triangulation[2]) and visual or image recognition techniques (Landmark recognition[8] [20], skyline recognition[20] and sun-tracking[21]) can be utilised to provide navigational services on Mars. Stereo visual and dead reckonning have been used successfully in previous missions (eg. Pathfinder [14]), but only over limited ranges and are not expected to be reliable techniques.

Dependence on a single technology is undesirable, so a combination of these techniques might be appropriate. Ideally, the establishment of a GPS-like navigation system around Mars would solve most of the expected navigation problems. However, systems that work without an orbital component are likely to be cheaper and able to be accessed in case of emergency or equipment breakdown and therefore should be strongly considered for development.

Moons	Units	Demios	Phobos	The Moon
Radius	km	6.1	11.2	
Mass	$10^{15}kg$	10.6	2.4	73000
Density	kg/m^3	1750	1900	
Orbital Radius	$1,000's\ km$	23.459	9.378	384.467
Orbital Period	$earthdays : hrs : min$	1 : 6 : 18	0 : 7 : 39	29 : 12 : 43
Rotational Period	$earthdays : hrs : min$	1 : 6 : 18	0 : 7 : 39	27 : 7 : 43

Table 3: Martian Moons - Physical Data Comparison with Earth's Moon [17]

Mars' moons, like the Earth's Moon, are in rotational lock with the planet they orbit. It may be possible to use them as relay station locations, triangulation nodes or elements in a satellite navigation system.

3.2.5 Weather:

The occurrence of large dust storms with wind speeds in excess of 30 m/s, dust devils and occasional global storms lasting months [24][12] place additional requirements on communications equipment. Even if ground staff are confined to the habitat, communications equipment needs to both survive the storm and continue to transmit through the storm (including the ability of the power supply to operate during severe black-out when solar panels are inoperative). The conditions in these storms do not seem to include the type of electrical activity (lightning) that we are used to on Earth.[9]

> Over decades of visual observations by both orbiting spacecraft and landers, no thunderstorms have been detected on Mars. Most likely, the Martian environment is too dry and too cold for such phenomena to form.

3.2.6 Habitation:

It is likely that the Martian explorers will need to defend themselves from an aggressive, unfriendly environment. It may be desirable to make habitats underground, as this will provide protection from the environment (radiation, dust storms). While there may be difficulties digging into the surface, which is expected to be principally composed of Andesite, underground habitats offer special challenges for communications. External connection issues including wiring, antenna and shielding design will need to be considered.

3.2.7 Environmental Hazards:

There are a large number of hazards facing an explorer on Mars. These may vary widely. Examples of the types of hazard that might be expected include.

- Atmosphere Contamination
- Atmosphere Loss
- Solar Weather Alert
- Power Level Low
- Dust Storm Warning
- Communications Outage
- Equipment Failure
- Medical Emergencies

It is intended that this paper concentrate on hazards which interact in some way with communications issues, typically where communications devices can help, or where lack of communication can hinder the success of the mission or the safety of the participants. Hazards which arise due to the long duration of the mission will not be considered directly. For example, any chronic exposure or deficiency issues will not be considered outside the rhelm of a medical condition requiring the remote communication of information. Issues such as isolation and the psyco-social impact on team members may be reduced using communication devices, but this is outside the immediate scope of the current investigation.

The urgency and severity of the hazard will vary. For example, impending dust storms may not be as critical as atmospheric contamination and slow atmosphere loss from a habitat may not be as critical as rapid loss of atmosphere from an isolated researcher's suit. These are communications issues and include decisions as to how urgent the emergency is and who needs to be informed.

4 Research Assistant

This section describes an information architecture designed to support Internet/Intranet searching from Mars for a potential Mars mission. There are 2 major hurdles in creating an information infrastructure to support a Mars mission:

- Information available only on Earth can only be recovered by traversing the Mars-Earth gap twice. Conventional Internet search engines are even worse as the Mars-Earth gap must be traversed 4 times to recover a document suggested by a search. Furthermore, the time delay is both variable (see figure 1), depending on the relative positions of the planets, and sufficiently long to be disruptive to the flow of work.

- Connectivity, except where hardwired connections exist, is likely to be intermittent.

To make an effective work environment the infrastructure must hide the existence of the time delays where ever possible and any information device must be able to provide at least a degraded service when not in contact with the network.

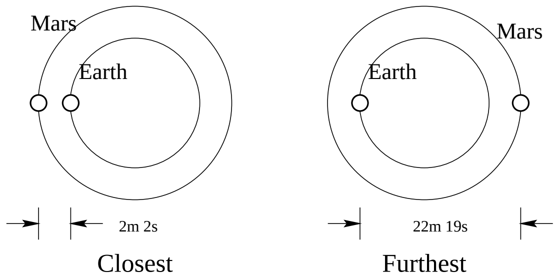

Figure 1: Time delay in the Mars-Earth gap (see table 1)

The information requirements of a Mars mission are assisted by having a well-defined corpus of knowledge that can be taken with the mission, updated remotely and can be used to answer many of the likely questions of the researchers.

Searching is conducted by software agents known as *Research Assistants* (*RAs*). *RAs* are located at each repository of information and at the gateway to the Internet.

Figure 2 illustrates a preliminary architecture that addresses the time delay issues and provides a partial service in the absence of connectivity. The information architecture employs archiving of the corpus of knowledge, caching of recent search results and pre-fetching of likely results to hide and potentially reduce the delays experienced by the researchers.

The architecture contains connections to the Internet, a group of experts, two copies of the *Mars Knowledge Base* (*Mars KB*), a communication link between the Earth and Mars, a cache of recently accessed information on Mars, and a wireless network to connect personal and vehicle mounted communication

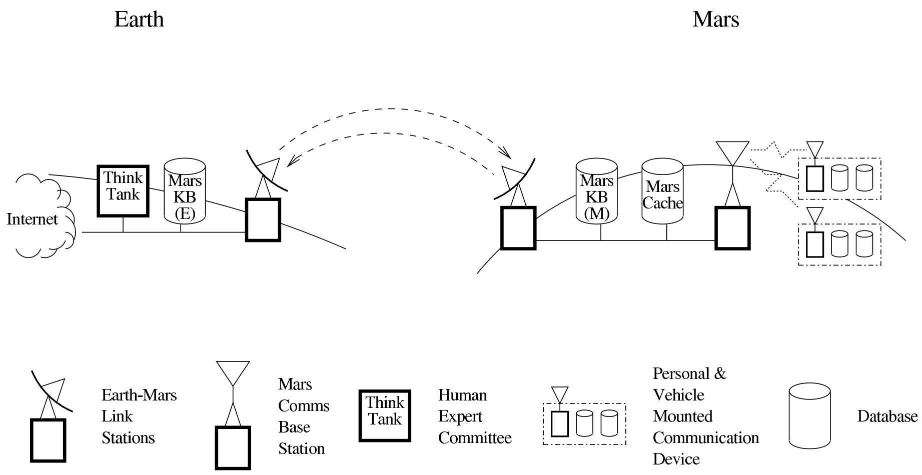

Figure 2: An Information Architecture for Research on Mars

devices to the Mars end of the network. These components are discussed in greater detail in the remainder of this section.

As the architecture is built upon an Internet infrastructure it supports existing and future Internet based applications including: e-mail, video conferencing, and Virtual Reality environments.

4.1 Earth-Mars Communication Link

The Earth-Mars Communications link is postulated to be a high bandwidth radio link transmitting digital data. Although it would be highly desirable for the link to be always available, it is likely that there will be not only service outages, but there may be periods when a connection is not possible. The level of service provided by the link will depend on the number of relay satellites employed in building the link. The worst case, if no satellites are employed[2], consists of a link outage of approximately half a Martian day per Martian day and a potentially greater outage if Mars is eclipsed by the Sun. Furthermore, there is a significant variation in the transmission delay.

The properties of this link suggest the following strategies to maximise the use of the link and minimise the delays noticed by human users:

- Forward error correction is mandatory to hide long retransmission delays.
- Routine or computer-to-computer messages should be queued to allow human directed messages to be sent first. This allows maximum use of the link and decreases the sense of delay that human users will perceive.
- Pre-fetching or pushing potentially useful results should be used to prevent a second round trip delay for human directed requests.
- Devices and software should provide at least a degraded service in the absence of the link as the link is unreliable.

[2]A direct link between a base on Mars and a collection of receiving stations on Earth

4.2 Mars Wireless Network

A range of wireless communications protocols and implementations are likely to be required to support a Mars mission. The following commercially available technologies serve as a starting point for devices that will be required.

Bluetooth [22] a short range wireless protocol designed for personal area networks. Suitable for transmitting voice and data. Data rate approximately $700kb/s$[15]. Range approximately 10 meters[15]. This protocol and its devices allow convenient penetration of enclosures and is designed for low power consumption.

802.11 a medium range wireless protocol designed for local area networks. Suitable for data transmission. Data rate approximately $5.5Mb/s$ for 802.11b and $35Mb/s$ for 802.11a[15]. Range approximately 100 meters[15]. This protocol and its devices are useful for short haul networks. With appropriate antennas this technology has been observed to operate over terrestrial distances in excess of 10 kilometres[6].

Microwave based point-to-point transmitters are widely available commercially. These devices provide line-of-sight transmission to the terrestrial horizon.

These technologies are based on spread spectrum radio techniques which provides some noise immunity and automatic management of noise and interference. Although Bluetooth and 802.11 have overlapping transmission bands this only results in a reduction in throughput, rather than disabling either technology.

Operating on Mars removes a number of strictures on the operation of these devices that can increase their operating range. In particular, high gain antennas and amplifiers can be used to increase the amount of available signal power beyond what is permitted by Earth governments. Directional antennas can also be used to improve performance.

The range of all these technologies are fundamentally limited to line of sight. The line of sight range is limited by the fact that the horizon is much closer on Mars than on Earth. Mars also has a higher topographical variation than Earth potentially further limiting line of sight.

Using these components it is possible to build a wireless data infrastructure (see figure 3) that easily links small man-portable devices back to a relay that permits access to the mars network. Small personal communication devices would use Bluetooth to link to peripherals such as audio headsets. These personal communication devices would then use 802.11 to access a local area network within close range (in excess of 100 meters) of a relay station or vehicle. Relay stations would then be linked either by amplified directional 802.11 or commercial microwave devices. Vehicles would need the support of omni-directional radio and relay stations or satellites. Field trials of relay stations (similar to the ones proposed here) and integration with satellites for data transmission have been carried out by NASA Ames Research Centre[1].

Using a layered approach to the *Mars Wireless Network* minimises the need to develop special purpose devices, reducing costs in design and manufacture. Using Bluetooth to provide short range communication is particularly desirable

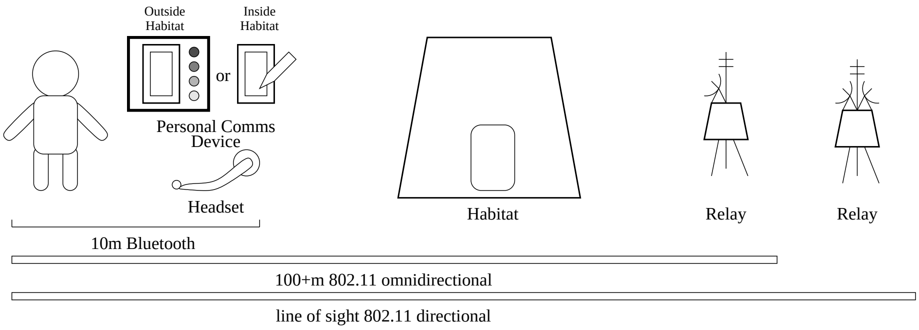

Figure 3: Mars Wireless Network

due to its low power consumption and easy access to commercial wireless devices. Local range and medium range directional communication can easily be accomplished using 802.11. Also, by employing 802.11 componentry in both relays and personal communication devices the spare parts inventory may be reduced. Long haul communication and omni-directional communication will require either purpose built devices or satellite communications.

4.3 Internet Connection

It is anticipated that researchers on Mars will wish to be able to send requests directly to the Internet. We anticipate that the researchers themselves will want this facility to maintain contacts with family and friends directly, and that the mission would welcome the potential positive publicity that can come from direct messages from Mars.

Issues such as network security and managing fan e-mail will have to be addressed at the *Internet gateway*.

4.4 Mars KB

It is anticipated that the researchers will take a collection of relevant works on Mars with them. This collection will be supplemented with their research notes and contributions from Earth. We refer to this corpus of knowledge as the *Mars Knowledge Base* (*Mars KB*). The corpus is compiled by human experts. Two definitive copies of this data base are maintained and they are updated using a synchronisation protocol. The copy on Mars is known as the *Mars KB(M)* and the copy on Earth is known as the *Mars KB(E)*. Other partial and non-definitive copies are maintained on other communication devices to allow access to this data when communication is unavailable. These devices update their copies of the databases from the definitive copies when required.

The Knowledge Bases hold the core information about the mission and the current understanding of Mars. The aim of centralising these records is to create both a backed up log of the mission and a first port of call for relevant detailed information on Mars.

4.5 Mars Cache

The *Mars Cache* is similar to traditional WWW proxy caches in that it fetches documents on the behalf of the searchers. However, it differs from other caches in that it retains information until the cache becomes full. The cache also supports a search interface. Furthermore, if a document has been accessed multiple times the cache will endeavour to fetch a fresh copy of the document in advance of the the document being required again. In addition to the simple caching of a document, the *Mars Cache* employs predictive fetching of documents. Predictive caching examines a fetched document and fetches documents that the the document refers to. To make this effective in the Marian context the examination of the fetched document needs to be performed on Earth and predictive documents need to be pushed to Mars with the fetched document. All these measures are intended to minimise the latency observed by researchers on Mars.

The predictive caching is entirely automatic. The combination of the *Mars Cache* and the *Mars Knowledge Base* should cover a substantial range of researcher requests.

4.6 Communication Devices

The proposed communications devices consist of:

- a ruggedised COTS (Common Off The Shelf) PDA (Personal Data Assistant) equipped with Bluetooth, 802.11 and a device for determining location
- a voice based radio
- an emergency beacon

The PDA will act as a researcher's personal terminal to access text and graphical information, store notes (including audio and video), and will contain a personal copy of the *Mars KB* and a cache of the documents that the researcher has most recently accessed. A personal *RA* will reside on the PDA. Voice is critical for communication in times of stress. Separating voice and data channels introduces a measure of redundancy to the communication fabric. An emergency beacon is at a minimum a psychological comfort, but also introduces a final additional channel for communication in case of emergency.

At this stage the final form factor is unclear. Three possible constructions include:

- Customised PDAs including voice radio and distress beacon
- Standard PDAs with modular voice radio and distress beacon backpacks
- Standard PDAs with the voice radio and distress beacon incorporated into a temporary enclosure.

Each of these alternatives involves differing engineering trade-offs, particularly in the areas of size and battery life.

Terrestrial ruggidisation is unlikely to meet the demands of operating outside the habitat on Mars. We envisage that some form of temporary enclosure would be used to protect the communication device. The enclosure would also contain heating, additional power supplies and a set of large robust buttons for activating facilities on the PDA. Part of the enclosure would be clear to allow the PDA's screen to be visible to the user. Furthermore, the enclosure will be transparent to radio waves allowing both the Bluetooth and 802.11 links to be used.

The benefits of using an enclosure over an armoured device are:

- the PDA remains personal equipment of the researcher and hence can be easily customised to their requirements
- the spare parts inventory can be reduced

4.7 Searching

Figure 4 shows how the communications infrastructure and the associated *RAs* interact to perform a typical query.

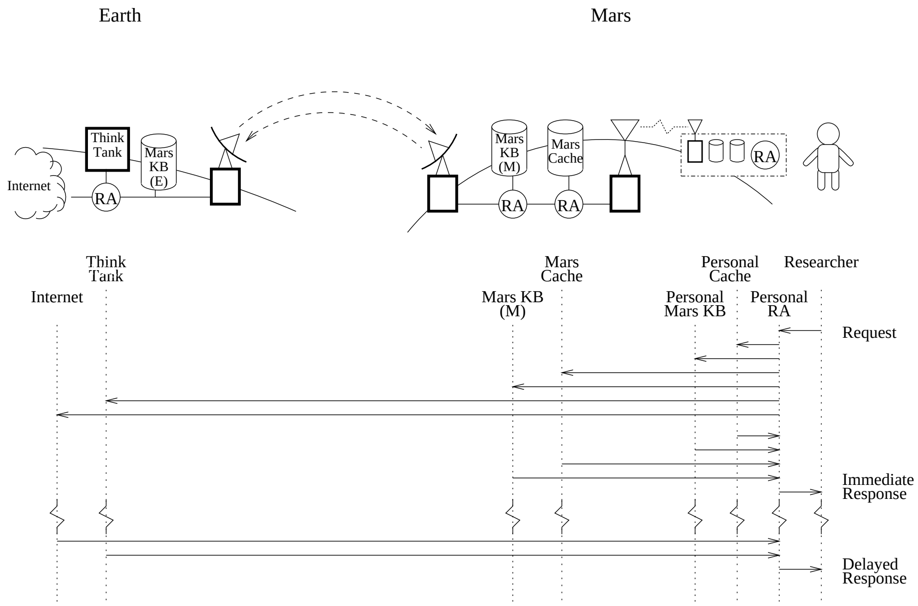

Figure 4: A typical search: Semi-interactive

To perform a search, the researcher sends a request to their local research assistant via a WWW interface. The researcher has the choice of:

Non-interactive sending the request all the way to Earth immediately and being notified when the delayed response arrives from Earth.

Semi-interactive sending the request to Earth immediately and also querying currently connected Mars based infrastructure. This will result in two responses: An immediate response from the Mars based resources and a delayed response from Earth based resources.

Interactive the request is only sent to Mars based resources and the result is delivered immediately to the researcher. The result includes an option to start a non-interactive search with the same inputs.

Searches are implemented by the local *RA* forwarding requests to other *RAs*. The local *RA* martials the results and reports them to the researcher. Earth based *RAs* may push documents which are considered to be highly relevant with the result of the search to make the documents available to the Mars based researcher without having to wait a second round trip time.

When the Earth-Mars delay approaches its maximum, it may be useful to employ the humans in the *Think Tank* to augment the automatic search tools. As the time period lengthens there becomes an opportunity for humans to react quickly enough to improve the quality of both search results and the set of documents pushed to Mars.

5 Experimental Support

The PDA found in the *Personal Communication Device* is used as a the primary tool for supporting experiments and experimental reporting. We envisage its primary use will be as a location augmented digital voice recorder with the ability to add segments of visual media from Bluetooth enabled cameras or instruments.

5.1 Voice

Voice is the preferred mechanism for recording observations when:

- Working in a stressful environment
- Operating equipment
- Moving

Although a full video record may be useful for some aspects of the mission, the greater storage and transmission requirements make video an undesirable media for routine reporting. Judiciously adding still and moving video sequences to voice based reports, we believe, will result in the most cost effective reports in terms of reducing bandwidth and storage and maximising content.

5.2 Location

Adding time and location information to a digital record eliminates the need for researchers to remember to include this information. In addition to reducing the load on the researcher, the accuracy and usability of the record as a historical document is enhanced.

5.3 Telemetry

In addition to location and time information other forms of telemetry can be added to the record. These elements could be contributed by polling nearby Bluetooth enabled devices.

5.4 Speech to Text

The linear nature of speech make it a poor media for the purposes of archiving, retrieval and editing. Text is far better suited to these tasks. Furthermore, considerable research effort has been invested into text based retrieval technologies. Thus we consider it necessary to convert the spoken notes of the researchers into a written form for the purposes of storage, retrieval and editing. This process is currently performed poorly by the best available software, however, by the time of the mission there is some hope of improvement. A software solution is not necessarily required as the audio information could easily be transfered to Earth for transcription. The transcript, supplemented with location information and any multimedia elements, can then be sent to the researcher for final editing before release.

6 Management of Command and Control

In this section we are not addressing the issues of schedule creation, it is assumed that a schedule has been created before the mission, instead we are addressing the issues of maintaining the schedule in the face of changing conditions.

The long duration of a Mars mission makes it quite likely that changes will have to be made to the schedule and tasks of the mission. These Command and Control (C2) issues need to be distributed to all relevant parties, a definitive version of the current schedule must be available and at times it may be necessary to determine the differences between the current schedule and one that existed at an earlier time.

One approach to managing C2 documents is based on the concepts of revision control employed in software. RCS[25] and CVS[10] are common source code revision control systems that allow differences between versions of documents to be displayed and tracked, furthermore, CVS provides a mechanism for automatically notifying users of changes to a document which they have a registered interest. CVS allows multiple users to update their personal views of a file and then provides a mechanism for identifying update conflicts. These programs operate by storing the set of differences between the current file and earlier files. The current file is stored in totality and the instructions required to change the file to an earlier versions are stored as well.

Extending the concepts of a revision control system to mission plan can be accomplished by specifying a time line and hyper-linking from the time line to versions of the descriptions of tasks. Changing the task description would result in notification being sent to registered parties, changing the time line would result in parties who participate in the union of the old and the new segment of the time line being notified.

A demonstrator for such a system could be built around existing revision control tools and a web interface.

C2 systems such as this have direct application to businesses performing scheduling and planning. The major challenge in constructing the Mars C2 system is coping with concurrency of updates. Existing Earth bound scheduling systems can use a single database and locking to ensure that world views are consistent. The large time delays prevent the use of such simple solutions.

7 Managing Messages

Long communication delays and time slip may well lead to a greater dependence on written communications similar to e-mail. As delays increase the natural flow of a conversation is disrupted; at the maximum delay of 44 minutes it is unlikely that a conversation can be effectively be conducted. Furthermore, the time slip associated with the differing lengths of day would make it difficult to have working relationship between two individuals using voice communication. It is unlikely that either the party on earth or the party on Mars would want to be out of sync with their respective diurnal cycles. Delay and slippage have less psychological importance for asynchronous communications channels such as e-mail.

Tools to manage correspondence with the least assistance from the user may reduce the load on the researchers/explorers.

Automatic sorting of e-mail into categories and priority would help in managing a potential information overload. There is a potential for the application of a existing AI (Artificial Intelligence) techniques to these tasks.

8 Research Issues

This section describes a number of open research questions and terrestrial opportunities to leverage the research that relate to the technologies described.

8.1 Usability

The *Research Assistants* and infrastructure and approach can easily be trialed on Earth for the purposes of determining how the researchers will interact with the system. The *RAs* also have application in other semi-connected networks, such as 3G and cellular networks and can be developed in this context.

The *Experimental Support* tools can also be trialed on Earth to refine their use. The key questions include whether voice commands can or should be used and developing suitable tools for editing the resulting supplemented dialogs and produced documents. These tools could have a wide application in both peoples personal and professional lives. The economic use of these tools on Earth relies on the accuracy of voice recognition technology.

Research into how best to support the management of user messages needs to be conducted. The technology is directly transferable into managing terrestrial e-mail.

8.2 Technology

Current scheduling tools do not handle the issue of simultaneous overlapping changes in the schedule well. Many systems seek to prevent the posibility arising by using locking. The C2 system resembles a scheduling tool for a semi-connected network and the solutions developed for the Mars C2 system could have direct application for terrestrial schedulers.

8.3 Cultural

The tools described have the potential to intrude into the privacy of their users. Work needs to be done on measuring the perceived level of impact on the privacy of the users and to enhance the acceptability of the tools.

9 Conclusion

This paper has identified a potential infrastructure for data communications to be used on a Mars mission that utilises a wide range of existing terrestrial technologies to minimise cost and maximise utility. In addition to the infrastructure, devices which access the data facilities provided by the infrastructure and support research and exploration note taking and observations have been described. Two further software centric applications have been described for managing Command and Control and text based messaging. Commercially relevant Earth based applications for these technologies have been identified.

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