PLANNING FOR EXPLORATION: THE MOBILE AGENTS 2005 FIELD TEST AT MDRS:

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ABSTRACT

The Mars Society's Desert Research Station (MDRS) Rotation 38, April 3-17, 2005, was dedicated to field tests of NASA's Mobile Agents EVA communications system. MDRS provided an excellent, cost-effective venue for bringing together teams from NASA Ames and Johnson Space Center, including six distinct projects, in an intensive two weeks of system integration and experiments. The flexibility of the Mobile Agents Architecture, the voice-commanding framework, and the empirical approach to requirements specification and development provide a powerful combination for development of integrated EVA systems.

INTRODUCTION

The project name, Mobile Agents[1], refers to software running on moving computers, communicating by a wireless network over a complex terrain of hills and canyons. The purpose of the project is to develop an Extra-Vehicular Activity (EVA) communications system that automates data management, workflow between crew and robots, and alerting and advising for navigation, scheduling, life support, and astronaut health. The system is based on the Brahms multiagent workpractice simulation language[2],[3], [4] Design of the current configuration is based on a combination of historical analyses[5], [6], baseline studies of field science[7], [8], experience in simulated missions, and previous MDRS field tests of the Mobile Agents systems[9].

The Mobile Agent Architecture[10] provides a flexible toolkit for configuring EVA components, visualizing and formalizing EVA plans, and automating key supervisory functions:

1) The EVA is formalized in a computer-readable plan.

2) The plan specifies players (people, robots, devices, software agents), roles, activities, locations, durations, alert thresholds.

3) The plan is created by the crew in collaboration with remote support, using visualization tools that promote reuse of previous plans and automatically translate to computer-readable form.

4) The plan is interpreted by agents to monitor the EVA, direct robots, interpret telemetry —for alerting (e.g., schedule limits, system health), advising crew (e.g., indicating next activity and how to get there), and recording data (e.g., indexed by time, location, activity, person)

5) The crew (either EVA members or in habitat/vehicle) can modify the plan during the EVA by voice command to change location or duration of an activity, repeat or skip activities.

6) Remote support teams receive emails tracking key events and alerts during the EVA, providing URLs to science and other telemetry data (stored in database in habitat mirrored to earth).

7) Plans can be specific to robots and individual crew members or shared to specify joint work (e.g., robot assistance is context-specific: following vs. repositioning to maintain network service vs. keeping station with tracking video).

8) Robots and devices can be controlled by a mix of voice commanding, tele-operation, or "autonomous" plans, allowing interruption and resuming of EVA plans.

During 2002-2004 field tests were conducted in Arizona (Desert RATS) and Utah to establish system connectivity and basic functionality. The current focus is to develop human-robot operations concepts and additional requirements while doing authentic geology exploration using the prototype system in a Mars analog environment.

OBJECTIVES

Our objectives this year were to demonstrate more improvised EVAs with the Mobile Agents system and coordination with two robotic systems:

- Adding to the EVA Robotic Assistant[11] (ERA) robot an arm with shovel and temperature sensor.
- Redesigned the top levels of the robot architecture to allow managing (start, stop, pause, resume, status) multiple tasks in parallel (e.g., join me, watch me, take a panorama, sample here) on a priority basis.
- Addition of a second robot (Thibodeaux) that might go 30 mph (and could be reconfigured to carry an astronaut).
- Completely reconfigured agent system for efficiency (e.g., location agent specializes in location name sharing and navigation responses)
- Improvements to voice commanding[12], including:
  - interacting with the robots to determine their status ("Whom are you following?")
  - "joining" with a robot (so it serves as a communications relay for an astronaut)
  - astronaut naming of work "stations" (1 m areas) within work sites
  - requesting locations and navigation information during the EVA
- Giving more responsibility to the remote science team for setting science objectives
- Routine use of planning tools for crew-RST communications, so EVAs were planned during the rotation, rather than being scripted.
- Automatic mapping of named places, photo locations, sample bags and voice notes onto dynamically stitched TerraServer maps, stored in the ScienceOrganizer database[13].

SYSTEM CONFIGURATION

The Mobile Agents system consists of several hardware and software layers:

- Networked laptop computers running the Brahms Virtual Machine (each with its own agent configuration and peripheral devices and software systems; see Figure 1),

- The MEX Wireless Network connecting the habitat, astronauts, and robots during an EVA (Figure 2), consisting of a wireless computing location area network (LAN) and KaOS server by which agents find the machine where other agents are running,

- Astronaut backpack systems, consisting of a single laptop computer, dGPS, audio headsets, and peripheral connections (Figure 3),

- The hub and IP address management system through which all laptops are networked and provided internet services (Figure 4).

EVA PLANNING AND ANALYSIS

As in previous years, the Mobile Agents team included the Mars Society's Remote Science Team, coordinated by Shannon Rupert (Figure 5). Protocols were designed to allow a three-day phase, consisting of ERA reconnaissance of a site, EVA planning using waypoints and photos provided by the ERA to the habitat, and an EVA with the astronauts and ERAs at the remote site.

The ScienceOrganizer system was augmented to automatically identify, download, and annotate aerial maps with the locations of EVA data (Figure 6). The numbering scheme identifies locations (e.g., waypoints and work stations), where voice notes were completed and where images were uploaded (but not necessarily taken).

RESULTS

The integration of the new robot architecture into the reconfigured agent system was demonstrated to work in dozens of tests around MDRS. However, we were unable to complete assembly of Thibodeaux or the arm on Boudreaux because of funding delays and parts burning out that were not stocked by vendors. Boudreaux was teleoperated using video frames broadcast to an operator in MDRS, serendipitously allowing tests for coordinating between the hab and EVA crew members.

An alternative Wide Area Network and Ku-band satellite system was configured in the weeks before the test because the previous provider, Glenn Research Center, lacked funding. This capability was supplied by an all-Ames team consisting of the Intelligent Mobile Technologies (IMT) Group, the Advanced Exploration Networks Group, and the National Research and Education Network (NREN).

A new mesh wireless LAN was deployed based on the Tropos product line. This mesh WLAN provides greater coverage and better dynamic routing than previous solutions. Significant work was invested in new repeater configurations deployable by robots, using a trailer and robotic arm.

A series of four rigorously planned EVAs demonstrated that the Mobile Agents system can be used for exploration of new terrain over two hours, including at least a dozen planned activities, planned on the same day by the crew (with advice from the remote science team's review of previous work). Furthermore, the astronauts could be left alone to work for long periods (20- 40 minutes) without prompting by the support team, or without their asking for guidance of what to do or where to go (this information is now provided by the agent system: Where am I? What is the next activity? Where is work site 5?). The crew member in MDRS supervising system operations has much less work to do than before, demonstrating progress in minimizing this function (the notion of "automating CapCom"). Nearly immediate response to voice commands demonstrated that the distributed wireless-agent system is now very efficient, though latency depends on computer network bandwidth (which requires careful configuration, even with omnidirectional antennas).

Voice Commanding Dialogue

With both astronaut backpacks working reliably and simultaneously, the possibility now occurred for complicated interactions between the people and their agents. Usually the geologists worked alone, as had been observed both in baseline (shirtsleeve) exploration in 2003, as well as in previous Mobile Agents system trials. However, on completing a phase, with the opportunity for alternative approaches, they came together to discuss the situation:

> B: This is pretty wicked, eh?
> A: It's kind of cool, just sitting here all by yourself.
> B: I know.
> A: So. Do you have a plan? How do you want to attack this? 'Cause we've got to stay pretty close...
>
> (pause)
>
> PB: Image collection, image-collection-four is associated with voice note voice-note-1.
> PA: Voice annotation was created. Do you want to associate voice note 3 with work site 10?
> B: I know, um, we could go....
> A: Yes (softly, to her agent)
>
> PA: Attempting to associate voice note with work site 10
> B: ... to the northeast and then work around our way here?.... Or start south... look at that way and then go north, and then back up to this same spot we've come up.

In this excerpt of about 30 seconds, there is first a normal turn-taking exchange between the geologists (A and B) lasting about 12 seconds. After a pause of less than 1 second, B’s personal agent (PB) indicates to B (A cannot hear this) that an image collection, which was created just before this excerpt began, has been associated with a voice note. After PB says “image collection four,” A’s personal agent also starts speaking, to confirm that a voice note was created and asks her to confirm the association. B replies as if to his agent, “I know um” and then starts to respond to A, “We could go.” But A is now replying to her agent and replies in a tone very different from her remarks to B, “Yes.” Now in the third section, 21 seconds into this conversation, A’s personal agent confirms that the association is being attempted, while B is simultaneously responding to A’s original question.

This is the first time we have observed the agents and astronauts speaking simultaneously, with three distinct interactions interleaved: A-B, PA-A, and PB-B. A and B can only hear their own agents, and if they do not use the press-to-talk button of their radio, only their agents can hear their responses. Nevertheless, the three interactions are simultaneous for nearly 10 seconds, and the agents clearly disrupted the astronauts’ conversation.

Each personal agent will not interrupt an astronaut while he or she is talking, but they will jump in when a pause occurs. Thus, A’s statement in the first part leads B to be silent, and PB uses this opportunity to announce the image collection information. Unfortunately, this occurs just as A has asked B a question. A’s silence allows PA to speak up, just as B is starting to respond to her, and she is forced to respond to PA while B is talking.

Many designs are possible to avoid having the agents interrupt people while they are talking to each other. For example, conversation between people could be detected as a time period when both are speaking in turn, and their utterances are not interpreted as commands to the voice system. If the agents exchanged this information, then the conversation activity could be detected and shared among the agents. Alternatively, we could allow the astronauts to actively turn on and off the agent interaction system, allowing only urgent interruptions. Or with many people working together, where monitoring multiple voice loops is difficult (e.g., in a dangerous situation working on a planetary surface), communications could be managed by an “operator agent” that would notify people that another person is “calling.”

The ATV/EVA Robotic Assistant

With the robots unable to provide proactive LAN relay support, we deployed instead Tropos repeaters by teleoperating a robot towing a relay on a trailer. We also demonstrated how a person operating an instrumented ATV could simulate a robot, which we called the ATV/ERA. (This idea was pioneered by Ames in 2002 as part of the Human-Operated Remote Science Experiment.)

The ATV/ERA is based on the IMT ATV design with on-board power, computing, LAN and wireless communications capability. It hosts the ERA's agent system (on a laptop computer) and a button interface on a Casio pen-tablet computer mounted up front. The interface computer is connected to the ERA computer by VNC login to a program emulating the ERA executor, which is also running on the ERA computer. Thus, when a voice command from the astronaut states, "Thibodeaux, follow me," the agent system on the ATV/ERA receives the command and translates it into a sequence of instructions the robot can execute. This information is received by the emulator and presented on the button display for the person operating the ATV to carry out.

The ATV/ERA system allowed us to test the new "join" voice commands that partner a robot with an astronaut, so the robot moves to sustain the astronaut's communications to MDRS.

This system will be useful at Ames for further development and testing when the ERA is not available. When Thibodeaux has been completed, we will substitute its robot executor for the emulator, and the robot should behave like the ATV/ERA.

The ATV/ERA can also be viewed as an astronaut's rover with an integrated pen-tablet navigation and exploration assistant. The rover could be further automated, for example, to provide emergency return of an astronaut to a habitat. In particular, Mobile Agents software running on the ATV/ERA could easily be used by the Scout robot at JSC.

The ATV/ERA method generalizes to allowing us to simulate a team of many robots using ATVs, which facilitates developing human-robot operations concepts before building the robots.

Crew Activity Analysis Tool

Foster-Miller, in collaboration with the first author, developed a system, called the Crew Activity Analysis Tool," for tracking crew activities which was tested during MDRS38 (Figures 7 and 8). The prototype system, packaged in a single case for shipping and field deployment, was delivered to NASA under an SBIR contract during 2005.

Interaction with Press and Visitors

Several Ames colleagues visited MDRS for about a week each, leading to designs for integrating the Mobile Agents system with planning systems that could generalize how the robots respond to multiple, sometimes conflicting requests from different people, plus tools to sketch EVA plans that will compile into formal models interpretable by the Mobile Agents system. Having potential collaborators visit during a field test is a valuable way to communicate and establish new working relations.

Several reporters visited MDRS38. Stories were published by the NASA News, Mars Daily, Space.Com, Salt Lake Tribune, San Francisco Examiner, and ErgonomicsReport (available at: http;//bill.clancey.name).

CONCLUSIONS

We had designed and implemented several complex scenarios for MDRS38, involving robotic reconnaissance of an EVA site (to establish waypoints), robotic deployment of computer network relays, and proactive movement of the ERAs to maintain network connectivity. Because of funding and organizational changes that affected budgets, we received equipment late and were unable to test this system until arrival at MDRS, which of course proved insufficient. However, the ATV-ERA configuration enabled us to experiment with the agent design and interfaces, and learn more about the challenges of placing relays in a hilly terrain obstacles blocking line of sight. We intend to pursue our designs in future tests insofar as funding allows.

The astronaut backpacks performed superbly during this year's tests, allowing extended, simultaneous exploration by the two geologists. For the first time in the five years of Mobile Agents development, the support group remained at least 50 meters away and often more, allowing the geologists a more realistic experience. With all agent systems working simultaneously and efficiently, we discovered that we are ready to move to the next stage of human-agent dialogue, so the agents do not interrupt people when they are conversing with each other.

Furthermore, with the fast and reliable behaviors in transmitting, storing, associating, and forwarding data, we found that much less confirmation was required for voice commands. The present system omits purely informative alerts (e.g., a voice note has been automatically associated with a location) and responds to requests that strongly fit the context of previous commands by a tone, rather than a question (e.g., "Continue recording voice note" is confirmed by a beep).

Our experience suggests that the flexibility of the Mobile Agents Architecture, the overall voice-commanding framework, and the empirical approach to requirements specification and development, provide a powerful combination for development of integrated EVA systems. We believe that approximately five years of continued development at the present pace of activity would enable a practical and reliable system to be designed, which could then be adapted for lunar missions planned for the second half of the next decade.

ACKNOWLEDGMENTS

In addition to fifteen contractors and civil servants from NASA-Ames and Johnson Space Center, people working at MDRS38 included two SUNY Buffalo geology graduate students (Garry and Semple), nine visiting colleagues, a part-time engineer, a reporter, and two researchers from Foster-Miller, Inc. (Judy Gertler and James Murray), for a total of 30 local participants. About a dozen off-site scientists constituted and supported the Remote Science Team. We thank Ray Gilstrap and Kevin Bass (NREN services, Ames) and Bill Notley, Ames Emergency Communications, for providing audio radio and Ames Ground Station Ku-band satellite support. Other support behind the scenes was provided by John Bluck (NASA Ames Public Affairs), the RIACS administration at Ames, and Mars Society volunteers who provided logistic support.

This project was funded in part by a NASA Research Announcement (NRA) through the Exploration Systems Research and Technology program. Funding was also provided within the Collaborative Decision Systems project. For more information about Brahms and Mobile Agents see http://www.agentisolutions.com; papers and press releases are available at: http://WJClancey.home.att.net.

FIGURES

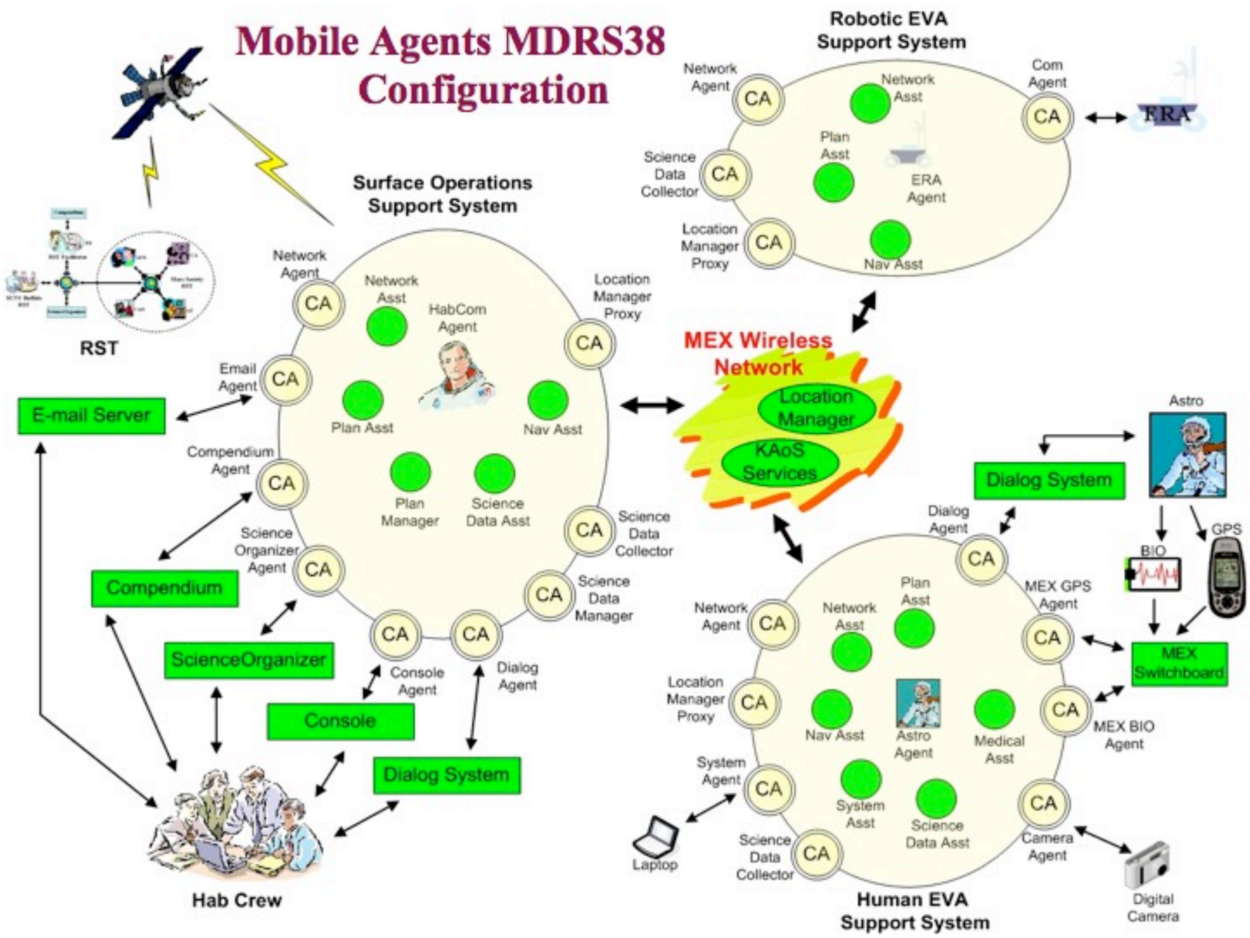

Figure 1. Mobile Agents MDRS38 Configuration includes more than 60 software agents on HabCom computer, two ERA robots, and two astronaut backpacks. Each of the five systems includes a "personal agent" for coordinating communications (command processing, alerting, and dataflow) with the associated person or robot. Specialized agents provide navigation, location name, medical, planning, science data, network, and computer system assistance as required for that person or robot. For example, the plan manager resides only in the HabCom system, while the astronauts have medical assistants. CA designates a "communication agent" which is implemented in Java and interacts with an applications programming interface (API) of some hardware device (e.g., camera) or software system (e.g., email, ScienceOrganizer, dialog system). Agents "find" each other in the MEX Wireless Network through the KaOS services and location manager which in this configuration must run on a centrally available laptop (e.g., on an ATV). (Graphic by van Hoof, Sierhuis, and Clancey).

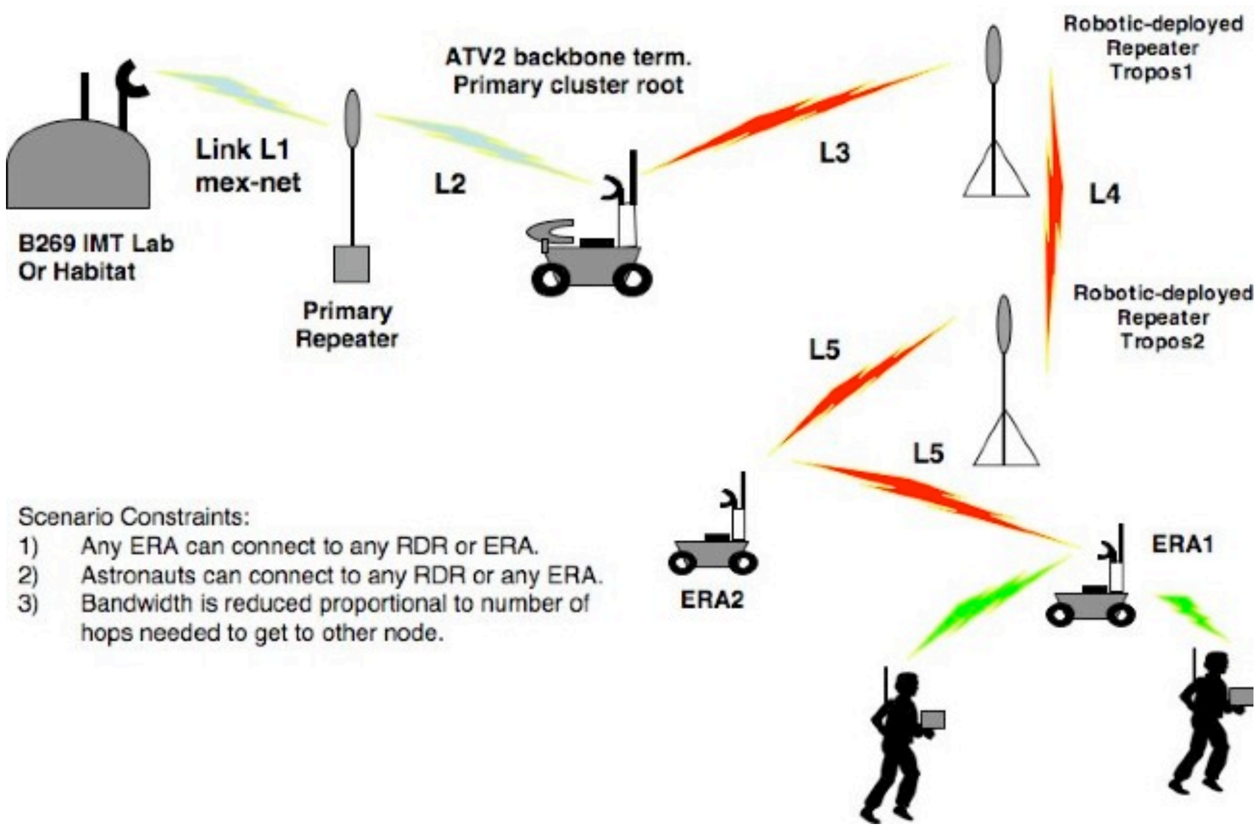

Figure 2. Most general configuration of wireless local area network for computer systems available for MDRS38 field experiments: Antenna on top of MDRS transmits to primary repeater located on hill towards east. ATV "primary cluster root" is then positioned for best coverage of planned EVA area. Two "robotically-deployed repeaters" (RDR) are optionally placed by robot or astronauts on ATVs. EVA Robotic Assistants (ERAs) optionally provide further network connectivity to the astronauts. (Graphic by Rick Alena.)

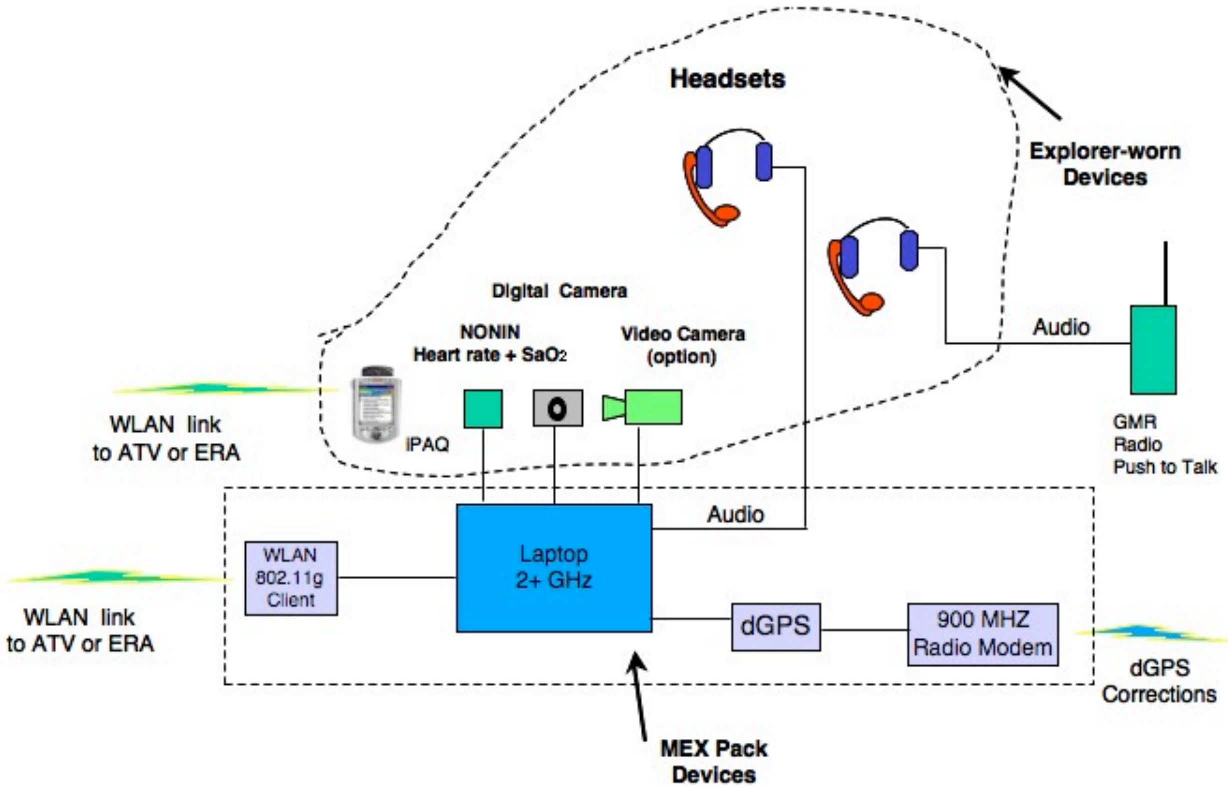

Figure 3. Configuration of computer system and associated equipment in each astronaut's backpack during MDRS38. Each system includes differential GPS, biosensors, and camera. One audio headset is used for voice commanding, the second for communications between people. (Graphic by Rick Alena.)

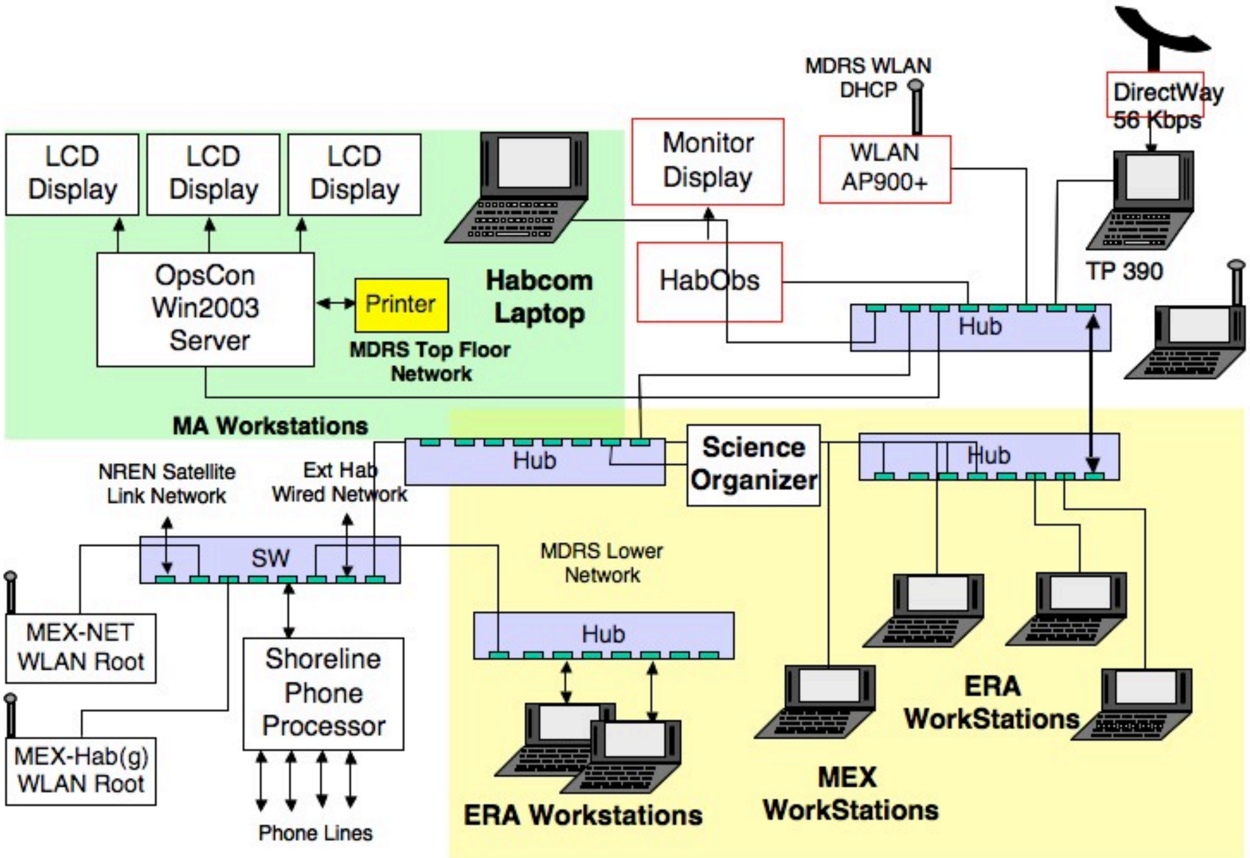

Figure 4. MDRS38 Computer and Wireless Network Schematic: Several dozen laptop computers are networked for Mobile Agents development and testing at MDRS, including personal systems in the habitat (upper left) and external computers for developing and controlling ERAs (lower right). Internet services are provided simultaneously by a TAZ satellite dish (NREN Satellite Link, lower left) and the MDRS DirectWay (for backup, upper right). An internet-based Shoreline Phone system is also available external calls. (Network design and graphic by Rick Alena.)

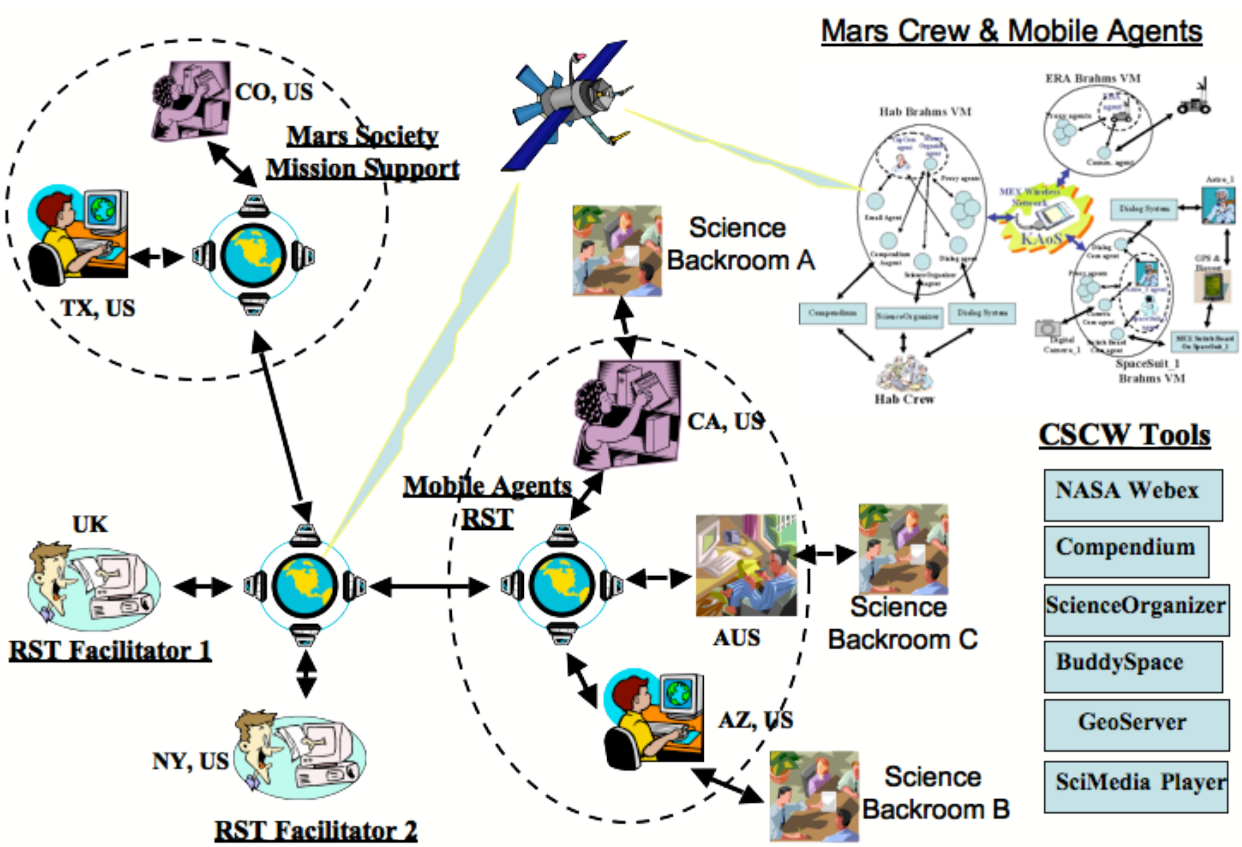

Figure 5. MDRS38 Remote Science Team: Crew is represented by graphic on upper right. Two RST Facilitators (in UK and NY) interacted with the Mars Society Mission Support team (CO and TX) and the Mars Society Remote Science Team organized by Shannon Rupert (CA, AZ, and Australia). The Mobile Agents RST in turn coordinated with other colleagues in "science backrooms." A variety of tools (see Clancey, et al., 2005) facilitated collaboration. (Graphic by Maarten Sierhuis.)

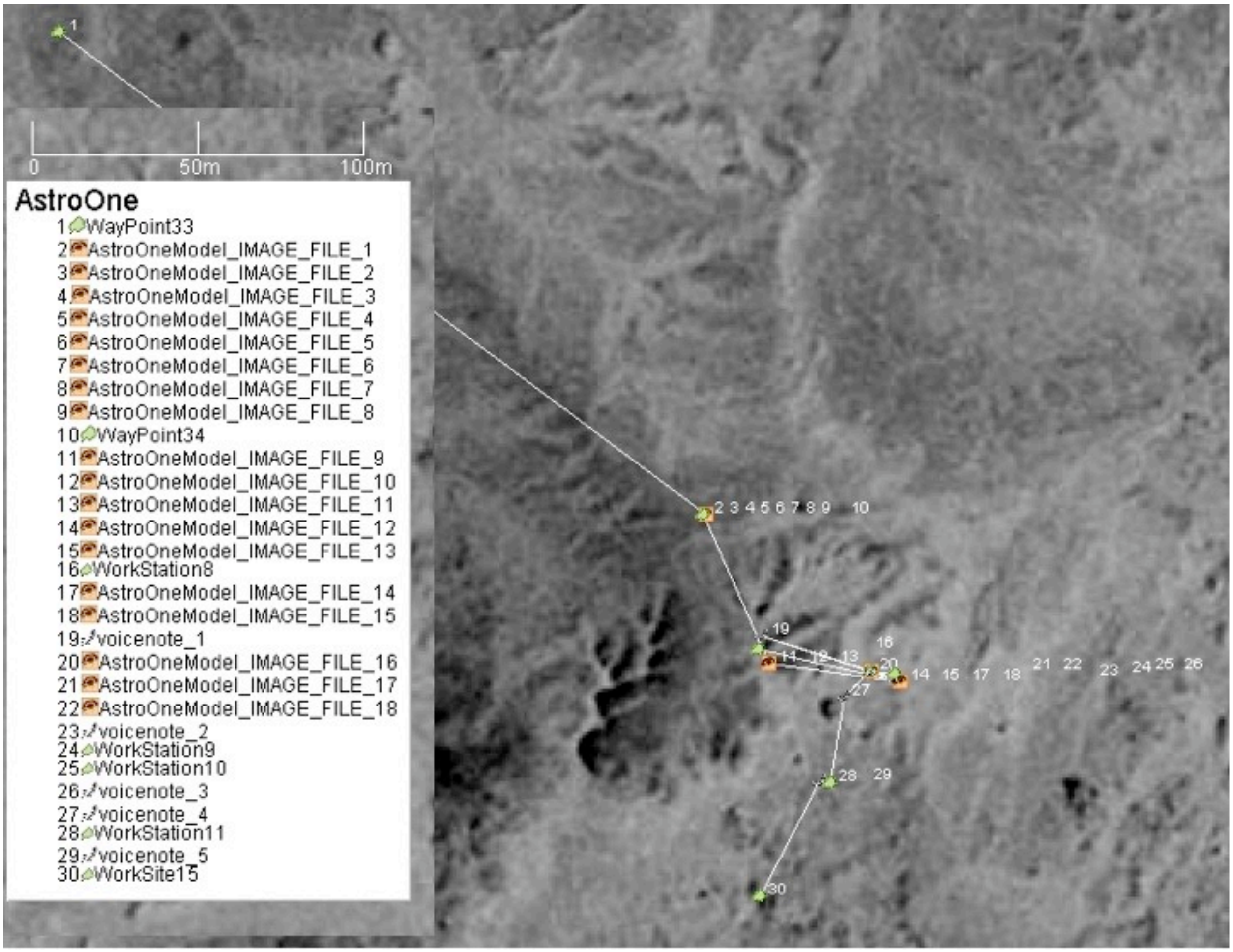

Figure 6. Map-based representation of an EVA generated automatically by the Mobile Agents system during the EVA, available to the RST by ScienceOrganizer: Data logged in ScienceOrganizer by the astronauts during the EVA is listed and numbered chronologically on right. Numbers correspond to locations on the aerial photo (from Microsoft Terraserver), where the astronaut creating the data was located when the data was uploaded. Numbers on the map may be double-buttoned to open the ScienceOrganizer web page where that item may be viewed or heard, and other data associated with the item examined via a hierarchical browser. (Implementation by Dan Berrios.)

Figure 7. Implementation of Crew Activity Analyzer (from bottom left): “Cricket” wireless transmitters are placed on crew member’s shoulders or worn on a hat (not shown: each crew member wears a wireless microphone); detectors are arrayed on ceiling of upper deck; one camera is above galley and 180 degree fisheye hangs above center stateroom door; computers in loft record and synchronize audio, video, and crew locations. (All photos by Clancey, except lower left by Jim Murray, Foster-Miller, Inc.)

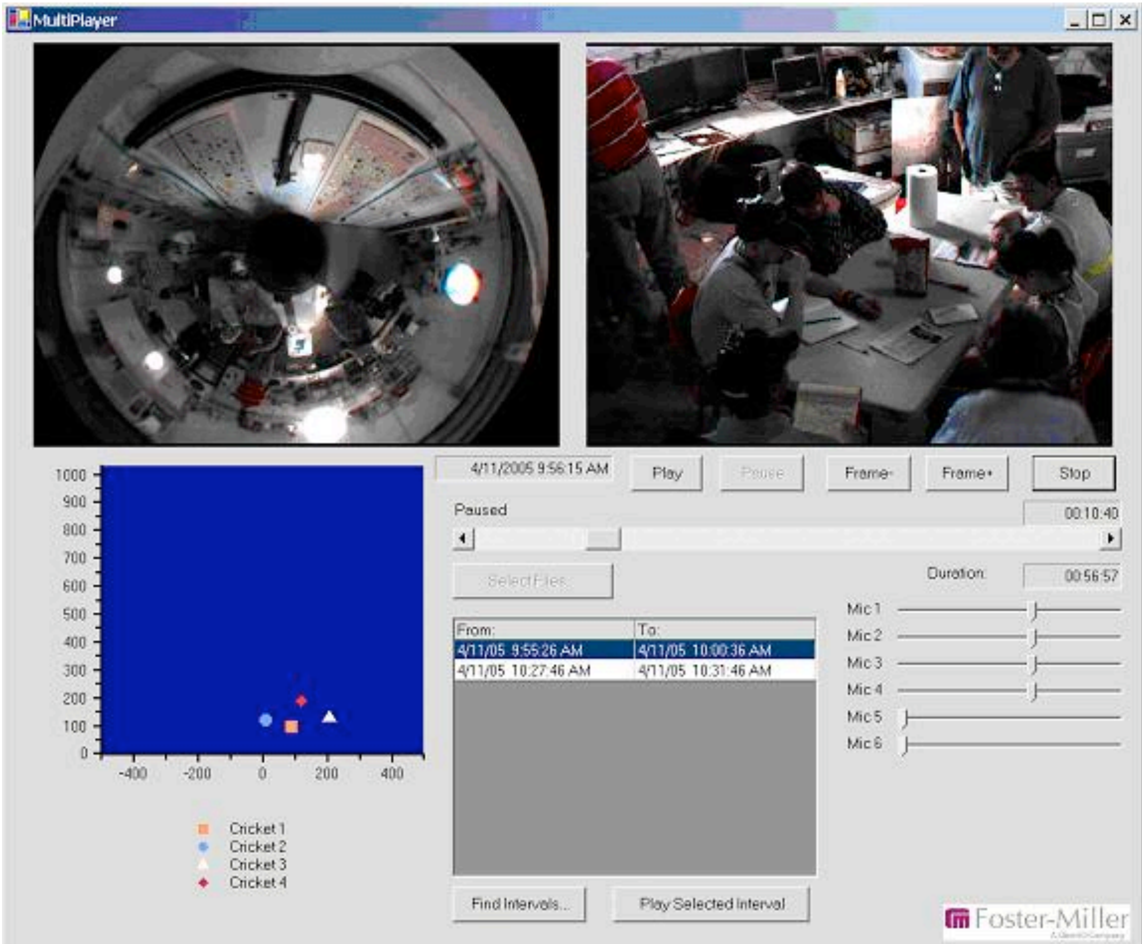

Figure 8. Crew Activity Analyzer tool allows playing back synchronized video (upper screens), and crew locations (lower left), with selected audio recordings (volume control, lower right). System is packaged to run on a single laptop computer. (Graphic courtesy of Foster-Miller, Inc.)

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