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CONSIDERATIONS FOR LUNAR COLONY COMMUNICATIONS SYSTEMS

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Abstract

This paper addresses system aspects of communications for a lunar colony. Human factors are particularly noted. The practical aspects of communications infrastructure are emphasized rather than specific technologies. Communications needs for mission support and morale are discussed along with potential means of satisfying them. Problem areas are identified and some possible solutions are considered.

COMMUNICATION SYSTEM OPTIONS FOR A LUNAR OUTPOST

I. Introduction

This paper responds to the request that a commercial practitioner having experience with remote communications systems and user needs apply that background to the communications needs of a proposed lunar base which will be designed for long term occupancy. Given this charge, a systems approach which emphasizes the application of readily available technology and the longer term needs of human occupants has been given primary attention, rather than aspects similar to those of past manned missions.

II. A Few Basic Ideas

First, much shorter design cycles and greatly expanded capability could be realized by using existing and projected telecommunications technologies which can be adapted to the lunar base environment. Since software is the major investment in modern communications systems, the largest -- and riskiest -- aspect of the development effort can be retained. Adopting commercial technology should also significantly lower cost.

Second, the duration of the mission implies different communications requirements than has been the case with previous Earth orbit and lunar missions. Based on experience with remote camps, the capability for occupants of the lunar base to interact as normally as possible with colleagues, family and friends on Earth will measurably improve work efficiency and enhance morale.

Third, current trends in telecommunications indicate that bandwidth requirements, particularly on the Moon to Earth link, will be larger than might be expected. Bandwidth usage will be driven by video, Local Area Network (LAN) interconnectivity and, to a lesser degree, by Command and Control data.

III. The Case for Adapting Commercial Communication Equipment and Software for Use in the Lunar Base

Taking these three points in order let's first consider that historically NASA has stayed off of the "bleeding edge" by freezing the design of systems many years before deployment. While this may prevent most mistakes from reaching the flight hardware stage, it also results in less than state-of-the-art mission hardware and software.

It is true that NASA's traditional conservative approach may still be necessary in fields that lack a vibrantly competitive commercial marketplace. But, in areas like communications, the dynamics of the market are such that a vast amount of parallel development work is undertaken, ideas are tried out, successful products and designs are accepted, and failures or poorly executed concepts are ruthlessly weeded out. To survive in such a market is to have demonstrated real value to the user.

An additional factor that makes commercial equipment and software desirable is the trend in recent years for users of communications technology to avoid the constraints and high costs of proprietary equipment and software systems by demanding that vendors conform their equipment and software to an "Open Systems" concept. This has given rise to so-called "Standards-based" systems in which interoperability is ensured by the development of standards that all vendors must adhere to. Such standards make it increasingly difficult for vendors to lock their customers into proprietary systems. What we see is a shift instead to a competition-based system where value is added to the basic specification in the form of useful features, enhanced reliability, user friendliness and, of course, lower prices. Today many manufacturers of computing and communications equipment, and increasing numbers of software developers, tout their particular products as being "Open" to indicate compatibility with products from other suppliers. A further benefit of the standards process is that ideas submitted for potential standardization are subjected to rigorous review by peers who are in many instances fierce competitors. While there is undoubtedly some game playing that occurs, ideas are refined into standards in a highly competent atmosphere where all stakeholders with a wide range of expertise have their say. The result is much more intense scrutiny than is often given to the specifications which drive one-off products in a non-commercial environment.

What does this have to do with selecting communications technologies for a lunar outpost? First, there is no reason to re-invent the communications wheel. The marketplace today has a rich set of equipment and software available for the mission discussed in this conference and that richness will only increase as the commencement date for the lunar mission approaches. To freeze the design too soon may place needless design constraints on other systems in the base as those systems would be unable to take advantage of as-yet undeveloped communications techniques which would exist closer to launch. Second, a higher performance communications system would result from the use of commercial communications technology since designing a system solely for use by this, or any, mission will necessarily result in taking a low-risk approach and forgoing many useful capabilities. For example, although more advanced technology was in existence at the time that the shuttle fuel cell controller was designed a safe design using relay logic was chosen. The range of capabilities would also be limited by budget constraints to only that set of technologies absolutely necessary for mission integrity. Alternatively, we can let the marketplace and vendors take the risk while we reap the benefits of being able to choose the most successful of those technologies and implementations from the widest possible array of choices.

Below are some examples of existing or emerging commercial communications technologies which may be useful in the lunar base under consideration here. These are certainly not all-inclusive but they should give an idea of what is possible.

1. Wireless and cabled Local Area Networks (LAN's) for networking both general and special purpose computers. Currently for very high bit rate LAN's fiber optics is the medium of choice using the ANSI X3T9 Fiber Distributed Data Interface (FDDI) standard which offers 100 Mb/s transport rates. (This may seem like an inordinately high rate until one considers that to transfer a 20 MByte CAD or image file at the currently popular 10 Mb/s Ethernet rate would take about 16 seconds not counting network overhead. Consider for a moment paging through a drawing suite with that kind of latency.) Wireless LAN's employing radio transmission are beginning to enter the marketplace and in the future may offer adequate transmission rates, at least for some applications such as data gathering or process control.

2. Personal Communications Networks/Systems (PCN's or PCS's). These new radio-based communications systems are one of the most hotly pursued developmental technologies today and should bring wireless telephones --estimated to cost under $250 and having full features and long battery life to the shirt pocket by the middle of the decade. While there are several communications technologies competing in field trials today, one, Broadband Code Division Multiple Access (B-CDMA), offers both high immunity to multi-path distortion, which commonly troubles current day FM cellular phones, and very low probability of interference into other systems. As interesting as the technology itself are the applications that are being developed around it. These include (a) the concept of number portability in which

a telephone number is identified with a person rather than a location, regardless of whether that person is at home, at work, visiting another office, in transit, or, perhaps, on the Moon -- sort of like using e-mail without having to log in; (b) active locator services in which the whereabouts of the owner of the telephone number can be determined; (c) and calling party identification which can be used to selectively screen or reroute incoming calls.

3. Networking technologies such as Switched Multi-Megabit Data Service (SMDS), Asynchronous Transfer Mode (ATM) and others. With minor modifications, these may make excellent candidates for the Earth-Moon link, offering very high data rates, switching, and the ability to combine voice, data, and image communications into one stream. Bandwidth can be efficiently and automatically shared among competing bandwidth users on a moment-by-moment basis, rather than the alternative of inefficiently dedicating bandwidth to individual communications users or projects regardless of use.

4. Existing and soon to be developed satellite Earth station technology which would be able to provide virtually off-the-shelf radio frequency and digital modem equipment for the Earth-Moon link, save for the antenna and support structure which would have to be specially designed for the lunar "outdoors".

Adopting commercial technology doesn't necessarily mean using commercial packaging or even components, neither of which may be suitable for the environment due to weight, configuration, or the range of conditions found during transport to the lunar shelter. The reality is that most of the design effort that goes into modern communications products is applied to software rather than hardware. Even if some redesign of the hardware were necessary to meet the requirements of the mission, the software -- where most of the effort and development risk lies -- is usable virtually as-is.

Even for communications equipment intended for use outside the shelter on the lunar surface most apparatus can be derived from commercial units by adapting commercial chip-sets to the rigors of the "outdoor" environment on the Moon combined with specialized packaging. While it may be necessary to produce special versions of commercial chips that are able to tolerate the high radiation and near vacuum environment, this should be much less costly than designing them from scratch in most instances.

IV. Human Factors In Design of the Communications System for the Lunar Base

Our experience with remote camps in the arctic and at the South Pole indicates that people need routine contact with their colleagues, family, and friends to continue to work efficiently and to maintain high morale over extended periods. Companies serving Alaska's remote resource development outposts, such as those on the North Slope and in the Bering Sea, are routinely required to provide for "morale phone" service to workers stationed there. Careful selection of personnel and training may help in this regard but there isn't any substitute for routine, high-quality contact with others outside the isolated group. In addition access to a wide variety of entertainment and news helps lessen the burden of isolation, particularly if individuals feel that the program selection is under their own control.

Given the current state of technology and reasonable development expectations there is no reason not to provide for these as well as the more traditional communication needs of a mission. Here is one possible hierarchy of communications technologies to meet these requirements:

- At the lowest level would be voice and data communications related to the security and integrity of the station. Included are telemetry and remote control of environmental systems and other equipment in the station as well as voice communication at a very basic command and control level. These critical needs are probably best provided for with systems similar to those used in the past which are independent of the more complex systems handling the bulk of the communications requirements.

- Next would be routine voice communication which could easily be handled on a dial-up basis. Each occupant of the lunar base could carry the equivalent of a pocket telephone supporting the features of an advanced PBX. This configuration would allow for each person to have a unique telephone number which could be called from anywhere in the world. In addition to the obvious efficiency implicit in the telephone network -- as refined over the past one hundred plus years -- integration into society would be beneficial in itself. Obviously, some method of call discipline must be imposed to prevent nuisance calls. This could be accomplished by screening on the originating caller's telephone number and/or a caller-dialed ID code. Once identified the caller would be compared against lists of authorized callers established for each person. These lists would probably vary by daily time periods such as working hours, off-duty time and sleep periods. Callers thus screened out could then be further routed to voice mail, an operator or simply denied access altogether depending on who they were. This controlled accessibility to Earthbound people, combined with the ability to simply place calls in the normal way to anywhere, including internally in the base or to personnel outside, would go far to integrating the lunar base personnel into the rest of the scientific and agency fabric which forms their resource group.

  A corollary to voice access to the public switched network is computer access to both private and public switched data networks for electronic mail, data base access, information services and the other data sources which can be reached via these networks. Similar access controls to those applied to voice communication would be necessary to prevent disruptive attempts to reach outpost personnel.

- The next level of complexity acknowledges that at times visual contact between parties is helpful. (For instance, imagine that all of the presentations at this symposium were given by telephone.) The rapid growth of video conferencing attests to both its usefulness in conveying graphic information and to people's desire to be able to obtain by observation the large amount of non-verbal communication that is lacking in a voice only telephone call. Video conferencing has grown dramatically primarily due to the availability of low cost video equipment -- especially the digital coder/decoder equipment which compresses the video and audio into a smaller and cheaper digital telephone channel -- and to the growing availability of the digital channels themselves. Video conferencing is useful for operational needs such as meetings, trouble shooting sessions and one-on-one conferences as well as for off-duty-hours personal morale calls to the base occupants' families and friends. Varying needs imply access to video conferencing equipment and channels from a variety of locations in the shelter, including work areas and individual living quarters. Both portable and built-in equipment would be needed.

Some circumstances would require only one-way video. These might be lunar vehicle cameras and the occasional media event. However, the same technology could be employed to transmit video of this type as would be used for video conferencing, perhaps utilizing higher bit rates to improve motion handling. Access to normal entertainment media channels could be provided by giving the station personnel access to an urban cable system. Full access to all channels would be available, but only the selected TV or radio broadcast channel would be relayed to the viewer at the station, thus minimizing transmission requirements. While broadcast video imposes much more difficult transmission standards than video conference quality systems to accommodate transmission of full motion video, advances in compression are occurring in this field as well. These developments take advantage of the point-to-multipoint nature of broadcasting by putting complex equipment at the sending location with simple decoders at the viewers' end. This technology is driven primarily by the direct to home broadcast satellite industry where radio frequency spectrum is limited and achieving the maximum number of channels of home entertainment video on a satellite means business feasibility or higher profits. Recently Comsat transmitted Super Bowl XXVI to a number of Navy ships in the Mediterranean using a prototype system. While it was not wholly satisfactory, it displaced only six voice channels on an Inmarisat maritime satellite. It is reasonable to expect that multiple channels of broadcast video and audio could be accommodated simultaneously giving residents of the lunar base significant freedom in choosing their own information and entertainment menus. Access to print media such as newspapers and magazines would also be valuable, although presumably in facsimile form to be displayed on a screen rather than printed. (One researcher who has wintered over at the south pole reports that the AP newswire was the best contact polar scientists had with the rest of the world. The very limited telephone calling ability at the pole allowed for no privacy.)

There are, of course, at least a couple of problems that must be dealt with. First, the Moon is about 1.3 seconds away at the speed of light. This means that twice that time, or 2.6 seconds, is required between the end of a spoken phrase and the earliest time that a response can be expected. Compare this delay with the nominal 6/10 of a second encountered in satellite telephone calls, and it's clear this long delay would be disruptive to normal conversation. Adaptation to long communication system delays, even when both persons are accustomed to the delay, can be only partial. Certain data transmission protocols, will have similar problems and will have to be fooled or "spoofed" into operating normally by a hardware/software interface or a "patch" that simulates the low-delay connections they were designed for. This problem has already been addressed for some time on satellite data circuits which employ protocols expecting the short delays associated with terrestrial channels.

All transmissions to and from the lunar base should be encrypted with an algorithm sufficiently secure that the possibility of intercept is insignificant. Doing so would protect the security of the project and would allow people at both ends of the circuit to speak unguardedly and openly. Nobody likes to think that a private conversation might be listened to nor will anyone speak frankly if privacy is in question. Private morale calls or other sensitive communications might be encrypted end-to-end to ensure absolute privacy. (This very lack of privacy has been cited on more than one occasion by people as a reason for not making calls to friends and family.)

V. Bandwidth

Some of the uses of communication on the lunar outpost may drive bandwidth (bit rate) consumption to surprisingly high levels. This usage will therefore influence communication system design, including the type of protocols employed.

Computing is increasingly distributed with many, if not most, computers attached to Local Area Networks. Communication and computing are harder and harder to distinguish with a trend for files and applications to be resident throughout the network. The size of files isn't getting any smaller either now that image technologies are being incorporated into what were once text-only systems. The larger number of LAN transactions is driving the development of higher bit-rate networks, beginning with 1 Mb/s Token Ring (IBM) LAN's in the 80's and graduating through 10 Mb/s Ethernet to current 100 Mb/s FDDI fiber optic LAN's with higher speeds in the wings. Network speed has increased as dramatically, as has use, with no let-up in sight. Of course it wasn't enough to connect computers in a single building, the need was more universal than that. Thus LAN's are increasingly connected together in what are called Wide Area Networks or WAN's. This technology is in a practical state of development but is not yet mature. Several competing and complementary technologies being developed today will make extremely large networks practical and cost effective in the future.

It seems likely that there will be a number of general purpose computers at the lunar base and that they will need to be interconnected with each other and to computer networks on Earth to gain immediate access, for instance, to the complete text and image documentation files for all of the station's components. Such transfers could require significant bandwidth, perhaps 50 to 100 Mb/s for a short period so that access to large image files could be accomplished within a reasonable time.

Video, both conference quality and entertainment quality can require significant and continuous bandwidth, especially if multiple sessions are to be supported simultaneously. The good news is that bit rate requirements for video conferencing have been steadily dropping over the past decade to the point that conference and videophone communication could be transmitted at from 64 to 256 Kb/s depending on the quality required. Entertainment video currently requires something on the order of 45 Mb/s. However, technology under development for direct-to-home satellite broadcast will reduce that requirement to the 2 to 3 Mb/s range.

By comparison, voice and instrumentation data rate requirements are small but may require committed bandwidth due to the time sensitive nature of such transmissions.

All of these uses of communications system capacity can contend for bandwidth-on-demand using technologies currently being developed or deployed in terrestrial communications networks. Transmission bandwidths in these ranges are in common use on today's satellite systems and pose no particular technological difficulty.

VI. Summary

In summary, it would be practical to adapt commercial technology to the bulk of the lunar base's communications needs, and, for the most part, to modify only hardware to suit the environment while retaining already proven software. The long- term needs of the human inhabitants will require more integration into the Earth environment than have previous NASA missions have, and transmission bandwidths will need to be much larger than expected.