

# SPACE AND TERRESTRIAL MEDIA FOR MILITARY COMMUNICATIONS: TECHNICAL PROS AND CONS

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## ABSTRACT

*This paper presents technical pros and cons for space and terrestrial media for defense-wide long-haul military communications. Today's defense-wide military space communications include use of leased commercial satellite capability in addition to the government-owned Defense Satellite Communications System (DSCS). The terrestrial communications include use of troposcatter, HF radios, line-of-sight (LOS) microwave, and metallic and fiber optic cables. The paper examines current usage, capacity, cost and other attributes of these media. Current trends and future uses of the space and terrestrial media for military communications are discussed. It is concluded that military communications will continue using a mix of both space and terrestrial media.*

## I. INTRODUCTION

The Department of Defense communications are categorized as: (1) strategic communications which support the global war related missions of the National Military Command System; (2) tactical communications for the Army, Navy, Air Force, and Marine mobile users on land vehicles, ships, and airplanes; (3) theater communications for the Major Commands and Commanders-in-Chief in theaters like Europe, Southwest Asia, etc.; (4) base communications for the local users located at posts, camps, stations, and bases worldwide, and their interfaces with the long-haul system; and (5) defense-wide communications for the long-haul, backbone needs of these users. This paper deals primarily with defense-wide communications and, secondarily, with theater communications and base communications. Since the Defense Communications System (DCS) is the long-haul, backbone communications system for defense-wide communications, the DCS will be at the center of the discussion. It is important to recognize that the above categories are not always clear cut, and that essential interoperability requirements exist between strategic, tactical, theater, base, and defense-wide users.

This paper will provide a brief overview of today's space and terrestrial transmission media for defense-wide communications, indicating which media are used, what each is used for, and the salient features of each. This paper will also address relevant technology developments, and, finally look at how these media will be used in the future.

Since defense-wide communications for the DoD is similar to long distance business and private

commercial communications between offices and homes, some of the same applications and trends that are relevant to commercial communications are also relevant to defense-wide communications. Of course, military communications differ from commercial communications because of the unique military requirements which emphasize survivability, security, interoperability, mobility, extensibility, and operation under crisis situations.

## II. TODAY'S SPACE AND TERRESTRIAL MEDIA FOR DEFENSE-WIDE COMMUNICATIONS

The DCS provides long-haul communications for the National Command Authority, the Commanders-in-Chief, the Army, Navy, Air Force, and defense agencies between fixed locations worldwide. It includes circuits routed by satellite, fiber optic cable, metallic cable, and microwave, troposcatter, and HF radio. There are hundreds of DCS transmission sites worldwide, most of which are overseas. DCS transmission serves voice, video, and data users of the DCS common user systems such as the Defense Switched Network, the Secure Voice System, and the Defense Data Network; it also serves users who require their own dedicated transmission. The DCS serves command and control traffic (from the National Command Authority to command centers), intelligence traffic, logistics traffic, weather traffic, administrative and other traffic.

From its inception in 1962, the DCS has depended heavily on line-of-sight (LOS) microwave, and metallic cable for both its leased transmission in the U.S. and its government-owned transmission overseas; it has also used troposcatter and HF. The LOS microwave radio stations, which are located worldwide, carry 26-90 Mbps traffic in each direction and are spaced about every 30-80 km. Metallic cables, also located worldwide, span from less than a kilometer to thousands of kilometers. Conditioned copper cables with twisted pairs can carry a T1 channel (1.544 Mbps) in each direction over 2 pairs. Typically a large conditioned cable has 1100 pairs and thus carries 849 Mbps (1.544 x 550) in each direction. Coaxial cables can generally carry 6 two-way DS-3 circuits (6 x 45 Mbps) per coax tube, and with 4 tubes per cable, they carry 1.08 Gbps in each direction. In CONUS, some metallic cables have been buried and hardened for enhanced survivability. Troposcatter systems owned by the DoD are used at a number of locations including Central Europe, Japan, the Mediterranean, the United Kingdom, Iceland, Greenland, and Canada. Troposcatter links range from about 150 to 600 km and can carry up to 10 Mbps in each direction. The majority of fixed site DCS troposcatter antennas are very large, resembling billboards; the sites are

frequently located on mountain tops. The DCS also uses HF radio, which has several modes of operation including ground wave, sky wave, and multihop sky wave. HF is used for long distance communications, covering distances from hundreds (ground wave) to many thousands (skywave) of miles. Today, HF principally provides analog voice and data (2400 bps) service to mobile users, such as tactical units, ships and airplanes, for DCS entry, and as a backup for satellite communications.

In the late 1960's and 1970's, geosynchronous satellite communications dramatically changed DCS transmission by providing high reliability, high bandwidth, low error rate, digital communications between earth terminals. The Defense Satellite Communications System (DSCS), which is one of several DoD satellite communications systems, has five active satellites on orbit providing worldwide service through hundreds of government-owned earth terminals with antennas ranging in size from less than 2 feet in diameter to more than 60 feet. Besides using the DSCS, DoD also leases satellite transmission in CONUS as well as overseas. The Defense Commercial Telecommunications Network (DCTN) uses leased satellite capacity from AT&T's TELSTAR satellites. TI capacities are also leased from CONUS to Alaska, the Azores, Bermuda, Hawaii, Panama and Puerto Rico, and from Hawaii to Guam. Of course, leased satellite communications does not provide the degree of survivability and security available with the DSCS.

In the late 1980's, the advent of fiber optic communications has once again started dramatic changes in DCS transmission. In CONUS, the telephone carrier companies which are leasing communications service to the DoD are rapidly changing to fiber optic media; over 70,000 miles of long-haul fiber optic routes are planned to be installed by 1989. Figure 1 shows the large mesh of fiber optic routes to be installed by companies like AT&T, GTE Sprint, MCI, WILTEL, Lightnet, etc. In the Western CONUS, seven east-west routes are planned. The mesh becomes even more dense east of the Mississippi River. In general, existing rights-of-way of railroad lines, gas lines, and cable lines are being used for these routes. Overseas, large fiber optic networks are also planned in Europe, Japan, Australia, etc. In South Korea, the DoD and the South Korean Government jointly installed a single mode fiber optic system. The DoD has also replaced metallic cables with fiber optic cables at a few other overseas locations, and is presently planning to install a fiber optic system in Central Europe. By and large, the cost of a fully U.S. Government-owned fiber optic system worldwide is prohibitive and is not being pursued. Leased host nation and commercial fiber optic cable systems seem to be the most practical approach.

In the past, the DCS has been leased in the United States and owned by the U.S. Government overseas. However, now there is a definite trend toward much leasing overseas as well. In general, transmission leased from commercial companies or from host nations will use the same types of media; i.e., LOS microwave, metallic cable, satellite, and fiber optic, but will not provide all of the military features needed by DoD. Importantly, they will not provide the aspects of security associated with U.S. Government ownership and end-to-end control.



Figure 1. Planned Fiber Installations in CONUS (Courtesy of Kessler Marketing Intelligence, Newport, RI)

### III. TODAY'S APPLICATION OF SPACE AND TERRESTRIAL TRANSMISSION MEDIA FOR MILITARY COMMUNICATIONS

Table 1 provides an overview of today's application of space and terrestrial media for military communications.

Table 1. Today's Application of Transmission Media for Military Communications

| <u>SPACE</u>   |
|--|
| <ul style="list-style-type: none"> <li>● LONG DISTANCE/TRANSOCEANIC</li> <li>● POINT-TO-POINT/BROADCAST/CONFERENCING</li> <li>● HIGH BANDWIDTH USERS</li> <li>● SHORT DISTANCE AND LONG HAUL BYPASS (VSAT)</li> <li>● RAPID EXTENSION/RESTORAL</li> <li>● DCS ENTRY/MOBILE USERS/NEACP/GROUND MOBILE FORCES</li> </ul>   |
| <u>TERRESTRIAL</u>   |
| <ul style="list-style-type: none"> <li>● SHORT TO LONG DISTANCE/TRANSOCEANIC (LOS, METALLIC &amp; FIBER OPTIC (FO) CABLE, TROPO)</li> <li>● POINT-TO-POINT (LOS, METALLIC &amp; FO CABLE, TROPO)</li> <li>● HIGH BANDWIDTH USERS (FO CABLE, LOS)</li> <li>● SHORT DISTANCE BYPASS (LOS, TROPO, FO)</li> <li>● RAPID EXTENSION/RESTORAL (HF, TROPO)</li> <li>● DCS ENTRY/MOBILE USERS (HF)</li> </ul> |

Satellites. Today, satellite communications have gained the preeminent position in long distance communications. For point-to-point communication at distances greater than several hundred kilometers, satellites are generally cheaper than either LOS or metallic cable; the exact cutover distance, however, depends on various conditions like the type of terrain and location of earth terminals. In addition, satellites which use digital communications techniques provide improved

reliability and performance that far exceed HF. The DSCS has largely replaced HF for long distance point-to-point applications in the DCS. With the unique capability of a geosynchronous satellite to communicate simultaneously with terminals located over about one-third of the earth's surface, satellites have opened up new broadcast and conferencing applications. Satellites can also provide wider bandwidths to serve imagery and television applications; these wide bandwidths are not available with most existing LOS and metallic cable systems which were designed principally for voice traffic. With the deregulation of the domestic telecommunications industry, Very Small Aperture Terminals (VSAT's) are receiving increased use by allowing the user to bypass the local operations company, the long-haul carriers, and the host nation's telecommunications system, using rooftop or backyard satellite dishes to provide direct user-to-user service. For example, VSAT's are used to provide 56 kbps links for access to the Defense Data Network (DDN) and for trunking between DDN nodes. VSAT's also serve requirements for low rate communications to a centralized processor and database. Satellite earth terminals can also be shipped to remote locations to quickly extend high quality communication where none exists. Satellites can provide real time coverage of everything from news events to crisis situations. Satellite earth terminals can be sent out to restore communications rapidly when other media fail, thus preventing long term outages. Where the expense merits it, small earth terminals, which inefficiently use satellite power, can be used to serve high priority users such as the President's National Emergency Airborne Command Post (NEACP) and major ships at sea.

Terrestrial. LOS and metallic cables are the preeminent terrestrial media for point-to-point applications. Metallic cable is pervasive in the local access area. For medium and long distance, LOS and metallic cable are used for point-to-point applications. However, use of fiber optic cable is growing, especially for high bandwidth applications; e.g., for trunking between the east and west coasts, and for other high traffic density routes. Fiber is also gaining use at locations which are short spurs off the main long distance fiber routes now being widely installed. For bypass applications, VSAT's remain the principal media; however, LOS, tropo, and fiber optics have received some use. For extension and restoral, HF and tropo media are used for certain applications. For example, tactical tropo is being used in remote areas where tropo can cover the distances between user nodes, such as in Southwest Asia.

#### IV. CURRENT MEDIA ATTRIBUTES

Capacity. First let us compare the capacity available in CONUS from satellites with that of fiber optic systems planned in CONUS. Today, a total of 28 domestic satellites serve CONUS (Source, FCC). These satellites are owned by AT&T (TELSTAR), Alascom (AURORA), COMSAT (COMSTAR), Contel (ASC), GE (SATCOM), GTE (GSTAR), Hughes (GALAXY), MCI (SBS), and Western Union (WESTAR). Four DSCS Satellites also provide CONUS service. In addition, five Canadian Satellites (ANIK) and two Mexican Satellites (MORELOS) also serve CONUS. Furthermore, some 15 more satellites will be launched in the near future, and some existing old satellites will be retired. A majority of existing domestic satellites

have 24 transponders of 36 MHz bandwidth with total bandwidth of 864 MHz. However, the recently launched satellites have 12 transponders of 36 MHz and 12 of 72 MHz bandwidth transponders and have a total bandwidth of 1296 MHz. Let us assume that in the near future, a total of 50 satellites with an average bandwidth of 1 GHz each will provide satellite service over CONUS. Assuming an average of 1 to 2 bits per Hz, the total satellite capacity will be 50-100 Gbps. The fiber optic cables currently being installed in CONUS have 8 to 36 pairs per cable with an average of 12 active fiber pairs per cable. Since, today, each fiber pair can carry 1.7 Gbps, the total capacity per fiber optic cable is about 20 Gbps. Since seven transcontinental fiber cables are planned in CONUS, the fiber optic media will soon offer 140 Gbps of bandwidth, which is 1.4 to 2.8 times that available with satellites. With the capacity per fiber pair growing rapidly, as discussed later in paragraph V, the fiber optic capacity available in CONUS will be even much larger in the near future.

Let us now compare the capacity of fiber optic with satellites for transatlantic traffic. The INTELSAT Corporation currently has seven satellites over the Atlantic each with a total transponder bandwidth of up to 2.46 GHz. Starting in late 1989, three of these satellites are planned to be replaced by higher capacity INTELSAT VI satellites. The recently launched PANAM satellite with a total transponder bandwidth of 1.3 GHz also provides transatlantic service. Also, two DSCS satellites are providing transatlantic service. Although current DSCS satellites have a total transponder bandwidth of 375 MHz at SHF band, in the future they will have a bandwidth of 1.3 GHz with the addition of EHF band capacity. Thus, the future total maximum transatlantic satellite bandwidth will be about 20 GHz. Again, assuming 1 to 2 bits per Hz on the average, the maximum transatlantic capacity will be about 20-40 Gbps. Transoceanic submarine fiber optic cables are being installed in the Atlantic, Pacific, and Mediterranean. Figures 2 and 3 show the planned submarine fiber optic cable routes in the Atlantic and Pacific Oceans. In the Atlantic, the TAT-8 cable is planned to provide 560 Mbps service starting in November 1988. The TAT-9 cable planned for 1991 will provide 1.12 Gbps service. In addition to these tariffed systems, a private non-tariffed high capacity fiber optics service will be offered by Private TransAtlantic Telecommunications (PTAT) Systems, Inc. The PTAT-1 submarine fiber optic cable, planned for 1989, will provide a capacity of 1.26 Gbps. The PTAT-2 cable will offer service at the same or higher rate. Thus, transatlantic fiber optic cables will soon have a capacity greater than 4.2 Gbps. Comparing the fiber optic capacity with satellites, it is clear that the transatlantic capacity available with satellites will still be greater than that available with submarine fiber optic cables by a factor of approximately 5 to 10.

However, satellites are subject to jamming and nuclear scintillation. Spread spectrum techniques needed for antijamming protection reduce the satellite throughput by several orders of magnitude. Antiscintillation techniques also reduce the throughput. Thus, the antijamming and antiscintillation maximum capacity available from satellites for military service will be several orders of magnitude lower than that calculated above

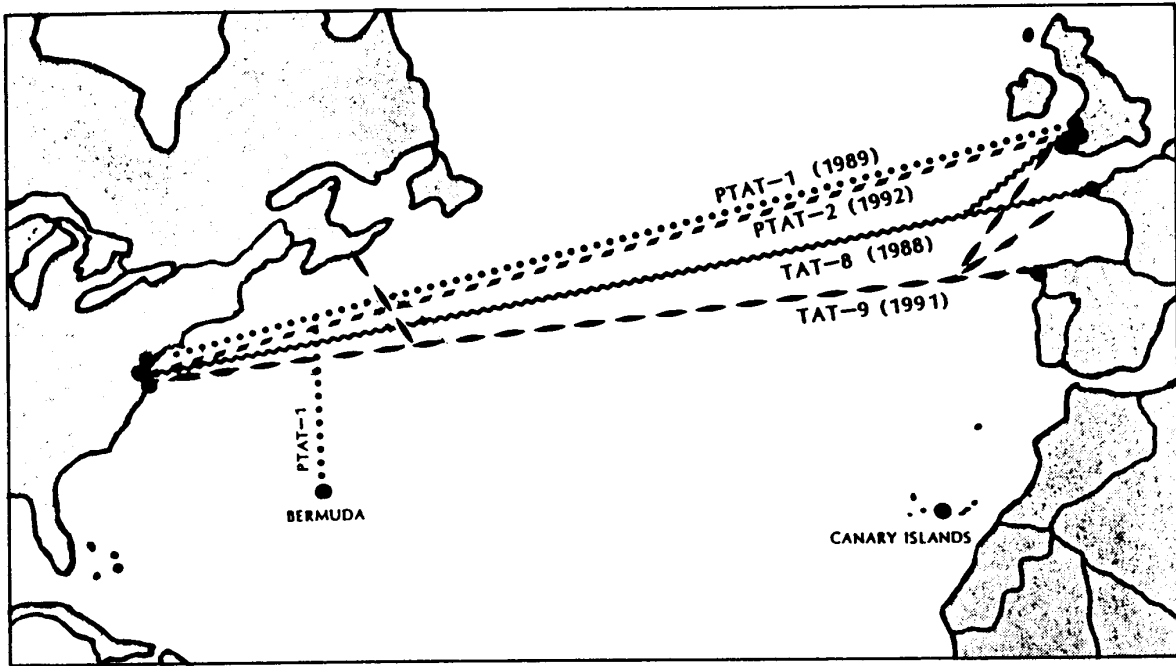


Figure 2. Planned Transatlantic Submarine Fiber Optic Cables  
(Courtesy of Kessler Marketing Intelligence, Newport, RI)

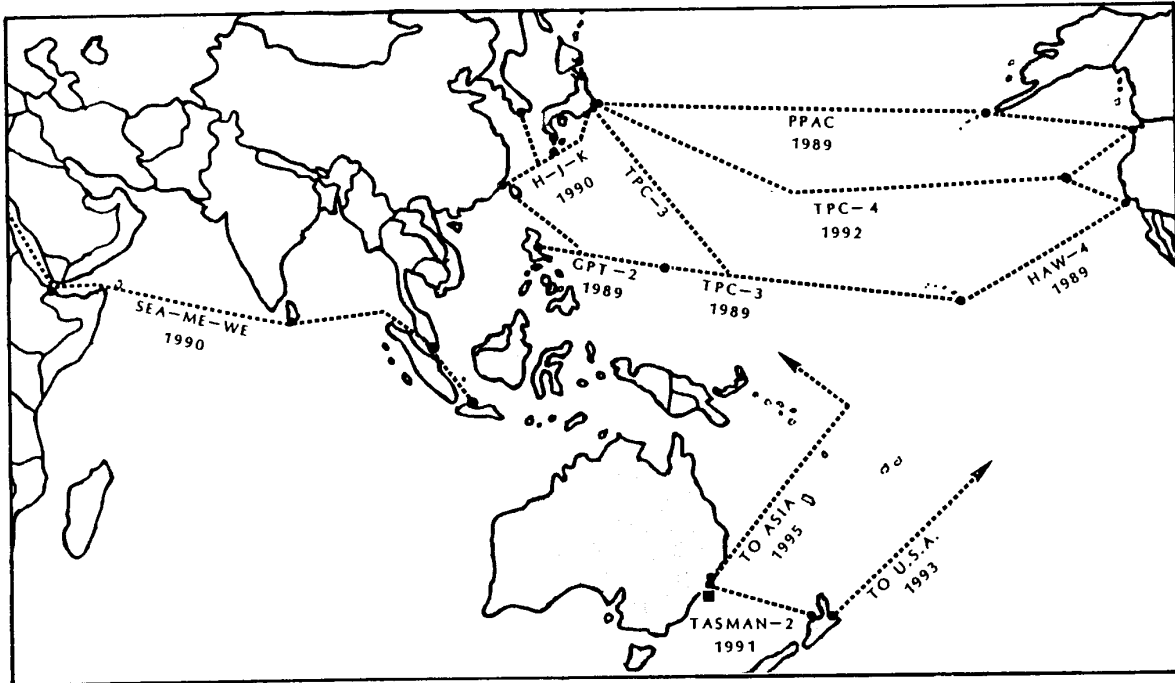


Figure 3. Planned Transpacific Submarine Fiber Optic Cables  
(Courtesy of Kessler Marketing Intelligence, Newport, RI)

which means that the existing and planned fiber optic capacity available for military traffic is already substantially larger than the CONUS and transoceanic satellite capacities.

Cost. Let us first compare the cost of satellite with fiber optic transmission in CONUS for a 25-year service period. The actual cost of providing satellite transmission is independent of distance on earth between users located at terminals within view of the satellite. The major cost of satellite transmission is for its space segment. The average cost of building a satellite and launching it (with insurance) is about 100 to 200 million dollars (Source, COMSAT and INTELSAT). For the 50 CONUS satellites assumed in the future (as considered for the capacity calculations above), the total cost will be 12.5 to 25 billion dollars assuming a 10-year satellite lifetime and a 25-year service period. The cost of installing fiber optic cable on land depends on a number of factors such as distance, cost of right-of-way, and type of terrain. The cost of installation is linearly dependent on mileage. However, the cost of installing cable through a city is generally higher than through rural areas and farmlands. Also, the cost will be much higher for uneven hilly terrain, and sometimes the cost can be prohibitive for rocky or icy terrain. The average cost of a fiber optic system in CONUS is about 50 to 100 thousand dollars per mile, and such a system has a lifetime of about 25 years (Source, GTE Sprint and LIGHTNET). The cost of the seven transcontinental fiber optic cables planned in CONUS will be 1.12 to 2.24 billion dollars assuming an average of 3200 miles per cable. Thus, if all CONUS satellites were used to provide transcontinental service, the satellite cost would be 5.6 to 22.3 times that for fiber optic cables. The total cost of the 70,000 miles of fiber optic cable planned in CONUS by 1989 will be 3.5 to 7 billion dollars. This is still less than the cost of satellite transmission which is even higher when the cost of earth stations is added in.

Next, let us compare the cost for transatlantic service for a 25-year service period. Assuming the cost of satellites at about 100 to 200 million dollars each, the total cost of 10 satellites over the Atlantic will be 2.5 to 5 billion dollars, again assuming a 10-year satellite lifetime and a 25-year service period. The cost of 6700 km of TAT-8 cables is estimated at 350 million dollars and the cost of 9300 km of TAT-9 cables is estimated at 400 million dollars (Source, AT&T). The life expectancy for these cables is 25 years. Assuming similar costs for PTAT-1 and PTAT-2 cables, the total cost of submarine fiber optic cables will be about 1.5 billion dollars. Thus, for transatlantic service the total satellite cost will be some 2 to 3 times higher than the fiber optic submarine cable, again not including earth terminal costs.

The cost and capacity comparison of satellite and fiber optic for CONUS and transatlantic service is summarized in Table 2. With the shuttle disaster and the phase out of expendable launch vehicles, the U.S. currently has very little launch capability. Although NASA is working hard to make the shuttle fly safely again soon, and industry and the Air Force are working to provide other expendable launch vehicles, many satellites are in storage waiting for launch

vehicles. This has not only increased satellite cost, but has also fueled the move to fiber because of the risk and uncertainty of satellite launches.

Table 2. Comparison of Capacity and Cost of Satellite and Fiber Optic for CONUS and Transatlantic Service for a 25-Year Service Period

| MEDIA       | CONUS TRANSCONTINENTAL          | TRANSATLANTIC                |
|-------------|---------------------------------|------------------------------|
| SATELLITE   | 50-100 GBPS<br>\$12.5B TO \$25B | 20-40 GBPS<br>\$2.5B TO \$5B |
| FIBER OPTIC | 140 GBPS<br>\$1.12B TO \$2.24B  | 4.2 GBPS<br>\$1.5B           |

Let us now compare the cost of fiber optic with LOS microwave. Figure 4 shows the cost versus capacity of a 100 mile circuit for LOS microwave radio, metallic cable, and fiber optic cable. This curve shows that for lower capacity requirements, LOS microwave radio is cheaper than fiber optic cable. However, for a capacity requirement of around 10 DS-3 channels (10 x 45 = 450 Mbps) or higher, fiber optic is cheaper.

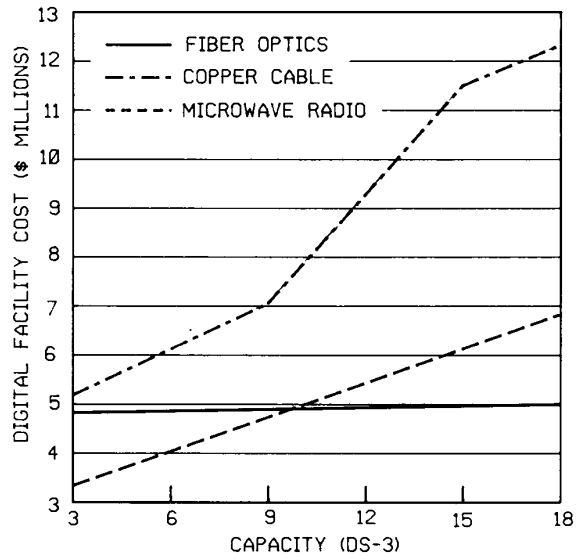


Figure 4. Cost Comparison Digital of LOS Microwave, Copper Cable, and Fiber Optics for a 100 Mile Route (Courtesy of Kessler Marketing Intelligence, Newport, RI)

Other Features. Besides capacity and cost, other features of satellites and terrestrial media are important in making a choice of media.

Satellites. Satellites are normally located in geosynchronous orbit at about 22,300 miles where they can simultaneously serve earth terminals located over about one-third of the earth's surface. The wide coverage area of satellites makes them uniquely well qualified for, and efficient at, broadcasting to a large number of sites simultaneously. This, in combination with the wideband capability of satellites (40 MHz to 100 MHz per transponder), explains why satellites are widely used for distributing and broadcasting television signals. The wide coverage area is also well suited to joining a number of locations in a video conference. TV video conferencing was introduced in the DCTN in 1986, and the requirements are growing. Since satellites see both busy urban centers and remote isolated areas, they are ideally suited for extending communications to remote sites. Satellites can also provide a ready backup to locations having an outage of the primary media serving them. With satellites it is possible to go from source to destination using just the satellite, thus avoiding additional costs of the local operating companies in CONUS and providing total U.S. control overseas without having to pass through host nation communications. Satellites also can provide a good average bit error rate of between  $10^{-4}$  and  $10^{-9}$ . This can satisfy all voice users and most data users. On the negative side, however, satellite transmission at the speed of light has a delay of 0.25 second per hop. A round trip delay of 0.5 second poses a serious delay problem for interactive data users and a noticeable annoyance to many voice users. The wide coverage of some satellite antennas make satellites easy to jam. Furthermore, the satellite channel is subject to various channel anomalies including rain attenuation and scintillation. Finally, earth terminals are easy to locate making them clear targets for either physical attack or downlink jamming. As technology advances, the satellite itself may be susceptible to physical attack by antisatellite weapons.

Terrestrial. LOS microwave transmission provides a very good bit error rate of between  $10^{-8}$  and  $10^{-9}$ , whereas the fiber optic media is even better with bit error rates of  $10^{-10}$  to  $10^{-12}$ . LOS radio links do not require rights-of-way as do cables; however, site approval is needed for the microwave towers. Fiber optic cables carry very high bandwidth, point-to-point traffic with very low error probability. Fiber optic cable neither emanates electromagnetic signals nor is susceptible to electromagnetic interference. Under nuclear conditions, fiber optic cable does suffer deterioration, but it recovers with time (about 24 hours) leaving only a small permanent degradation in error probability performance (by a factor of 2 to 4). HF and tropo (and LOS for short distances) can provide for extension of communications to remote areas and for rapid restoral of communications disrupted due to outage. On the negative side, terrestrial transmission media are not well suited to broadcasting or conferencing to many locations. Rights-of-way are needed for cable systems, as are frequency allocation and approval for most radio systems. Cable and LOS systems make easy targets for sabotage, attack, etc., and are difficult to secure physically. Large billboard tropo antennas are vulnerable to air attack. HF and tropo do not provide as high availability as cable, LOS, and satellite.

## V. TECHNOLOGICAL DEVELOPMENTS AND IMPROVEMENTS IN MEDIA ATTRIBUTES

Space. To avoid congestion of the SHF frequency band and to provide antijamming protection at higher data rates than SHF can deliver, DCA is looking to use the EHF band in addition to the SHF band for future DSCS satellites. A large number of EHF band technological developments are being accomplished for both the space and earth segments under the MILSTAR program and also by industry. These include various antennas (thin phased arrays, gimble multibeam, agile beam, solid state active aperture) and high power amplifiers. These developments will be exploited by the DSCS, and an initial EHF capability at 44/20 GHz is anticipated for the 1990's. Autonomous control techniques for satellites will reduce operational cost and dependence on vulnerable control terminals. Improvements in hardware parts (solid state amplifiers, antennas, etc.) will reduce the life cycle cost of satellites. On-board processing in the space segment will improve the capacity under jamming. Developments in satellite-to-satellite crosslinks will improve survivability and decrease the delay by eliminating the need to double hop through vulnerable relay nodes when communicating from a terminal in one satellite coverage area to a terminal in another coverage area.

Terrestrial. There are large number of technological developments in the area of fibers, cable connectors, photo detectors, lasers, and edge-emitting diodes. Research is being done for using coherent detection and also for using all-optical regeneration/amplification versus electro-optical regeneration as is done today. All these improvements are aimed at increasing fiber optic bandwidth capacity while reducing its cost. In their laboratory, AT&T Bell Labs has demonstrated a fiber optic pair carrying 27 Gbps at a 60 km repeater spacing. Figure 5 shows the trend in the increase of bandwidth capacity and repeater spacing for a fiber optic pair. This curve shows that there will be a tremendous growth in the bandwidth capacity of fiber optics, and a capacity of 100 Gbps at a repeater spacing of 100 kilometers will be within reach in the next decade. In their labs, AT&T Bell Labs have recently sent light pulses over 2480 miles of fiber without using any repeaters. A very large fiber optic network is planned worldwide. Large fiber optic networks are planned in the United Kingdom, France, Germany, Japan, etc. Planned installation of a larger fiber optic network in CONUS was discussed in Paragraph II. AT&T forecasts that by 1991 over 93% of their circuit miles will be using fiber optics. The Bell Operating Companies have also already started the installation of local fiber optic loops in metropolitan areas. The total local fiber optic route mileage will be much larger than that for long-haul. By the mid-1990s fiber optic connectivity between major locations around the world will be a reality. Special upgrades are being developed on fiber optic cables and associated equipment to substantially reduce the degradation due to nuclear effects. Old metallic cables are being replaced by fiber optic cables. LOS microwave links will stay until very high bandwidth requirements will make it economical to change to fiber optics. New LOS microwave links will be added only at places where rights-of-way or terrain

problems make it impossible to use fiber optic cables. For example, in Alaska, where terrain problems make fiber optic media less attractive, LOS microwave is being used for the backbone, and satellite media is being used for providing video capability at various stations.

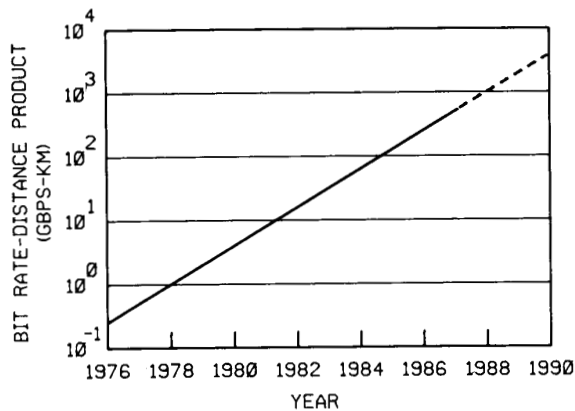


Figure 5. Capacity Trends in Fiber Optics

With technological improvements in modems, equalization, and diversity combining, data rates higher than the current rate of 135 Mbps will be used for digital LOS microwave. Work is also in progress for the development of 15/23 GHz LOS millimeter wave systems for providing high capacity transmission for short distances. Improvements in digital troposcatter include equalization techniques, angle diversity techniques, and efficient high power amplifiers. Meteor burst developments offer a low capacity, high survivability media during crisis situations, and for low capacity extension and restoral. Automatic link establishment standards are being developed for the HF media; this will significantly improve the operational availability of HF communications while reducing required skill levels.

#### VI. CHANGING MILITARY REQUIREMENTS

Although voice requirements are growing steadily, data requirements are growing very rapidly and are expected to exceed voice requirements by the mid-90's. As a result of lessons learned in the Lebanon and Grenada incidents, there is an increased emphasis on command and control voice and data conferencing. The DCTN provides a video conferencing capability and the requirement for this capability is growing. Imagery and other wideband applications continue to grow. There is an emphasis on readiness, and on survivability in a nuclear environment.

#### VII. FUTURE APPLICATIONS OF TRANSMISSION MEDIA FOR MILITARY COMMUNICATIONS

Table 3 provides an overview of future applications of transmission media for military communications. Because of their unique

Table 3. Future Applications of Transmission Media for Military Communications

- **SATELLITE**
  - CONTINUE TO LOSE GROUND TO FIBER OPTICS FOR POINT-TO-POINT LONG DISTANCE AND TRANSOCEANIC BUT CONTINUED USE FOR BACKUP
  - CONTINUED USE FOR SERVING HIGH BANDWIDTH USERS
  - CONTINUED USE FOR BROADCAST AND CONFERENCING
  - CONTINUED USE FOR REMOTE AREAS, FOR RAPID EXTENSION, AND FOR RESTORAL OF OUTAGES
  - INCREASED USE FOR MOBILE USERS (TRUCKS, SHIPS, PLANES, LAND VEHICLES)
  - CONTINUED USE FOR BYPASS
  - CONTINUED USE WHERE END-TO-END NATIONAL CONTROL IS REQUIRED
- **FIBER OPTICS**
  - RAPIDLY INCREASING USE FOR TRANSOCEANIC; LONG DISTANCE; AND SPURS OFF OF LONG DISTANCE ROUTE
  - INCREASING USE FOR LOCAL AREA THROUGH WIDE AREA TO CONNECTION WITH LONG HAUL, RESULTING IN PERVASIVE FIBER OPTIC CONNECTIVITY
- **LOS MICROWAVE**
  - STEADY DECREASE AS FIBER OPTICS GROWS
  - CONTINUED USE FOR ROUTES NOT ECONOMICAL FOR FIBER (LOW BANDWIDTH; HOSTILE TERRAIN E.G., ICE OR ROCKS; NO RIGHTS-OF-WAY)
- **METALLIC CABLE**
  - CONTINUE FOR LOW BANDWIDTH ROUTES UNTIL END OF LIFE
  - NO NEW INSTALLATIONS OR REPLACEMENTS FOR LONG DISTANCE AND TRANSOCEANIC; SAME LATER FOR WIDE AREA AND LOCAL AREA
  - GRADUAL PHASE OUT, TO BE REPLACED WITH FIBER
- **TROPO**
  - PHASE OUT EXCEPT FOR REMOTE AREA EXTENSION AND RESTORAL, AND FOR SPECIAL CASES
- **HIGH FREQUENCY (HF)**
  - CONTINUED USE BY MOBILE AND TRANSPORTABLE USERS
  - CONTINUED USE FOR SOME EXTENSION TO REMOTE AREAS AND RESTORAL OF OUTAGES
- **METEOR BURST**
  - USED FOR LOW DATA RATE EXTENSION AND RESTORAL OF OUTAGES
  - USED FOR HIGH SURVIVABILITY COMMUNICATIONS REQUIREMENTS

characteristics, and because of the requirement to use multiple media for backup and higher survivability, both space and terrestrial media will continue to be heavily used for future military applications.

**Space.** A major drawback of satellite transmission is a delay of 0.25 sec from source to destination. Although satellites are widely used today for point-to-point transmission, the use of fiber optics is growing rapidly because of its very

wide bandwidth and lower cost. More and more, fiber will replace satellites for point-to-point communications. Satellite communications will still be used as a backup to fiber and also to provide a mix of transmission media to enhance survivability. The use of satellite for transoceanic service will continue but with a reduced share as compared to today. AT&T has signed an agreement to guarantee COMSAT that about one-third of the new overseas traffic will be sent via satellite until 1994 (Washington Post, 21 August 1988). Satellite will continue to be used for serving high bandwidth users, especially at EHF band, and for jam resistant communications. Satellite has the unique broadcast feature, and will continue to be used for broadcast/video conferencing. It will continue to be used for rapid extension/restoral, for mobile users, for providing connectivity between tactical systems and the long-haul DCS, and for bypass. Satellite transmission offers the unique advantage of total national end-to-end control over the transmission assets and thus will certainly continue to be heavily used for critical command and control, and intelligence traffic.

Terrestrial. Fiber optic media has the unique advantage of providing enormous capacity at a very low error rate and lower cost. It will be the predominant media for long-distance transmission. Its use for transoceanic service will grow. The use of fiber optic for local area will also grow. With the emergence of new high bandwidth services like Broadband ISDN, high definition TV, or access to high bandwidth data bases, fiber optic cables will even replace local metallic cables in the future. Standards are already being considered for Broadband ISDN 150/450 Mbps services. Microwave links will be added only where laying fiber optic cable is not possible (right-of-way required) or not economical (lack of high bit rate requirement or terrain problem). Metallic cables will be phased out at the end of their life, and will be replaced by fiber. Because of high O&M cost and high physical vulnerability, fixed site troposcatter links will be used solely for rapid extension situations. HF will continue to be used for extension/restoral/DCS entry/mobile users. Meteor burst media will be used for special low data rate applications, restoral applications, and for high survivability communication requirements.

#### VIII. SUMMARY

This paper has addressed various space and terrestrial media and their current and future application. The driving factors for selection of media are cost, bandwidth, distance, constraints (frequency allocation and orbital restrictions for satellite, rights-of-way and terrain problems for fiber optic, and frequency allocation for LOS), and requirements (survivability, mix of media, control over communications assets, broadcast, conferencing, extension/restoral, mobile users, delay, and error rate). Satellite transmission will be used to satisfy the requirements of broadcast, conferencing, total control over communications, and rapid extension/restoral. Fiber optic will be used for large bandwidth, low error rate, point-to-point transmission where the right-of-way and terrain constraints do not prohibit it. Because of their unique characteristics and because of the mix of media requirement, both space and terrestrial media will continue to be used for military

communications, but with much more emphasis on selecting the media based on its unique attributes to accommodate the desired application rather than its being the "only game in town." There will also be much more tailoring and specialization of applications to better capitalize on the different attributes of the future defense space and terrestrial transmission systems.

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