Key technology trends – Ground terminals

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This paper presents an overview of the status of pertinent technologies for the ground segment of communications satellite systems. It is derived from the 1997/98 NASA/NSF sponsored commercial communications satellite study of technology, markets and services. It is recognized that the ground system technology is often more important than that of the satellites, especially as satellites are increasingly being used to provide services directly to the end-customer. The current state of technology for several classes of ground terminals is reviewed. This includes Very Small Aperture Terminals (VSAT) for Ku- and Ka-bands, Television Receive-Only (TVRO) Terminals, handheld terminals, portable and mobile terminals for multimedia and business use, airborne and ship-borne terminals, hubs and gateways and military terminals.

Keywords: Satellite communications, earth terminals, VSATs, hubs, gateways, mobile terminals, hand-held terminals

1. Introduction

This Paper reviews the status of technologies for the ground segments of communications satellite systems. It is based on material from the WTEC Panel Report Global Satellite Communications Technology and Systems, December 1998 [1].

In 1992 the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) commissioned a panel of US satellite engineers and scientists to study international satellite R&D projects in order to evaluate the long-term presence of the United States in this industry [2]. In the five years since that study, the satellite communications industry has become an even larger industry than most had predicted, increasing from $11 billion in 1992 to $20 billion in 1996. Far from being supplanted by fiber or other communications networks as some suggested would happen, satellite technologies and architectures are expanding as more countries establish communications satellite capabilities. With the technological advancements of the industry and its worldwide growth, NASA and NSF commissioned a panel in 1997 to update the earlier study and also extend the scope to include additional countries. This study included also policy and regulatory issues that are becoming increasingly important to this global industry.

This paper will highlight changes since the previous study conducted in 1993 and emphasizes developments that are both new and important.

While the hundreds of satellites have been the symbol of progress in satellite communications, the millions of ground terminals in all frequency bands represent an equally profound achievement. The ground segments now comprise a large portion, if not the majority, of the total cost of a new system. Satellites and terminals have tended to be independently produced, suggesting that they are in fact independent (with notable exceptions). But in recognition of their significant percentage of system cost, the relationship of satellite system design and terminal design – and ultimately terminal cost – have become more openly recognized and debated. Design activities for personal and mobile consumer-oriented systems that demand low cost terminals are largely responsible for the increased visibility of this important principle.

Much cost oriented terminal design has been taking place since the 1993 study, and is implicit in the maturation of mobile and personal systems. The same principle must be employed in the future for consumer and business user Ka-band multimedia systems. An aspect of the terminal design consideration is the need to exploit the cost versus quantity relationship [3].

The anticipated continued growth of VSAT networks and satellite television broadcasting, and the introduction of personal and mobile systems and direct-to-user-services, together provide a broad basis for anticipating a very large future market for satellite communications terminals. In general, cost will decline

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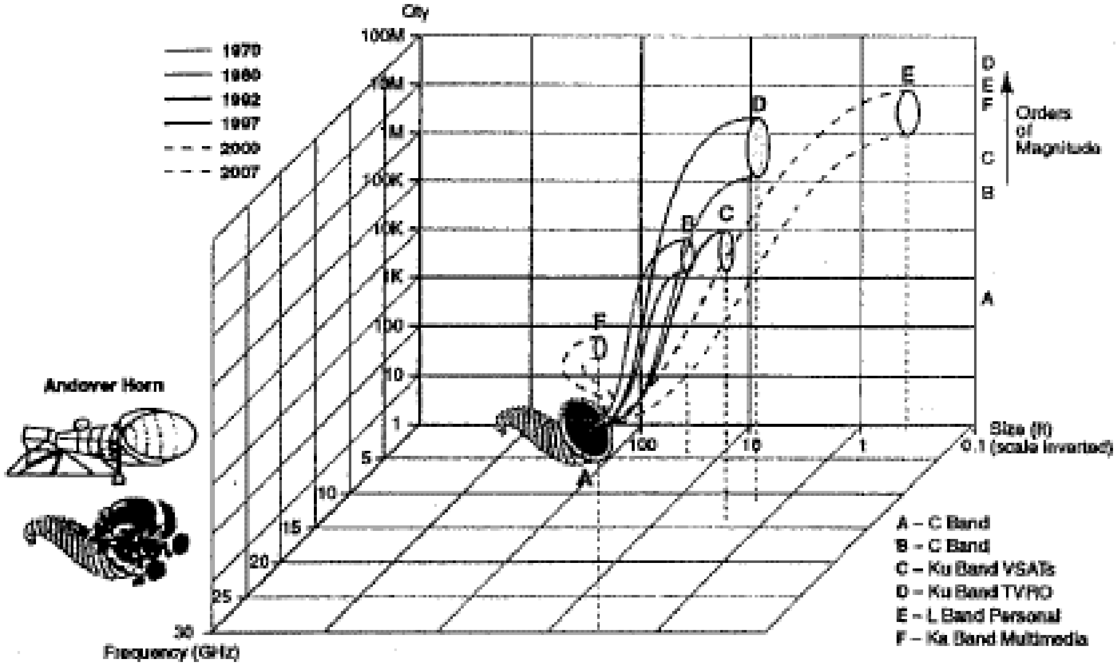


Fig. 1. Evolution of satellite terminals in number of terminals, frequency and size (1965–2007).

as a function of large quantities, lower frequency and smaller size. The original US ground terminal at Andover, Maine employed a steerable folded horn, 54 m in length and a corresponding aperture of approximately 26 m. A folded horn resembles a cornucopia; and the Andover horn is, in fact, a beginning point or inspirational source for all satellite terminals. Figure 1 depicts the present and predicted future populations for five classes of terminals discussed in this section. This chart depicts the evolutionary trajectories in quantity, size and frequency space, flowing out of the Andover horn. Quantities reach into the millions for several classes. The figure summarizes both the actual history and a future projection.

Major trend-making terminal classes with future impact are discussed in this section. Several classes, including news gathering terminals, are not discussed.

2. VSATs

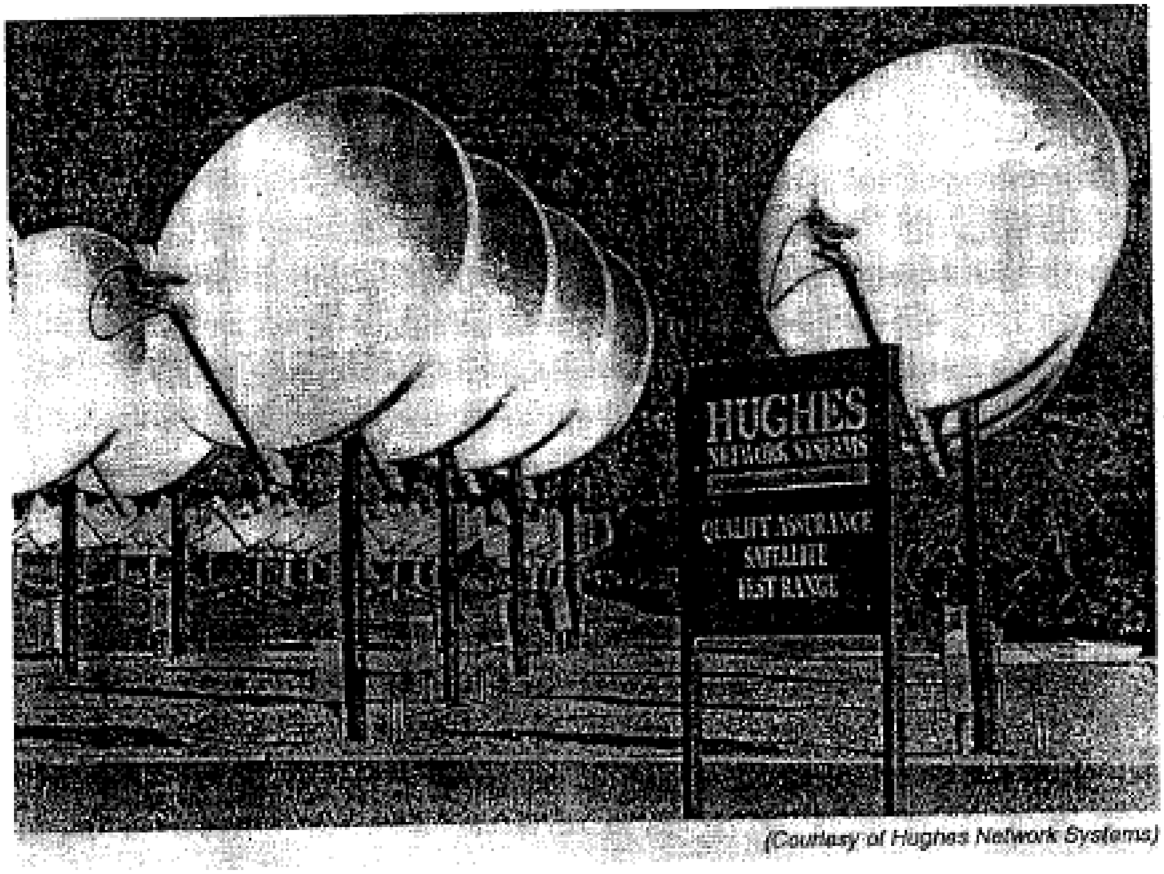
Very small aperture terminals (VSATs) have extensive uses in business and government and are anticipated to have expansive roles in future Ka-band systems. VSATs are here considered to include a transmit capability. Small receive-only terminals are a separate category.

In developed countries, the ability to bypass existing infrastructures with a private network has achieved cost savings. In less developed countries, the possibility of establishing a distance-insensitive, modest cost network, using a satellite transponder with VSATs and a hub station, enables many cost-effective applications. The broad generality of VSAT uses and applications will enable continued worldwide growth.

2.1. *Ku-band VSATs*

The majority of VSATs operate at Ku-band. The worldwide number is difficult to determine with any precision. We estimate that by 2000 there will be at least 500 000 two way VSATs worldwide. Considering the needs in Asia, Africa and S. America, the number should easily double within ten years.

While Ku-band is allocated for fixed service, an airborne Ku-band VSAT exists and there has been much activity in developing airborne receive-only array antennas. Historically, C-band VSATs were allowed through introduction of spread spectrum signaling that prevented interference (due to broad beamwidth of C-band VSATs) to adjacent satellites. Similarly, OMNI-Tracs is a mobile (vehicular) service (at Ku-band in the United States and Europe, at C-band in Latin America). It may be that similar spread spectrum techniques will allow introduction of airborne VSATs in Ku-band.



(Courtesy of Hughes Network Systems)

Fig. 2. VSAT terminal quality assurance test range (Hughes Network Systems).

The VSAT consists of an outdoor unit-antenna with low noise amplifier (LNA) and power amplifier located at the feed to minimize line loss, and a MMIC low noise down converter – and an indoor unit (down converter and digital electronics that vary depending on the application). With the advent of large quantity production, VSATs may be integrated from parts available from many sources. Much experience is needed for volume production of high reliability units. Figure 2 shows a group of VSAT outdoor units at Hughes Network Systems being operated to assure reliability before shipment.

2.2. *Ka-band VSATs*

A number of Ka-band systems are planned for providing wider bandwidth (>10 kbps to 100 kbps) and 'wide bandwidth' (~1.5 Mbps to 155 Mbps) services to small VSATs (~45 cm to 60 cm diameter antennas). These systems are based on providing video conferencing, private 'intranet' services, telemedicine, teleeducation, direct two-way Internet access and multimedia communications of the future. As described, the systems are a new type of fixed satellite service (FSS).

Many of the envisioned services and applications would be offered to the private or home user. There is broad consensus that the VSAT terminal for consumer application must be carefully engineered for a total price to the consumer of $1000 or less. Systems providers are engaged in defining means for accomplishing this goal. While details are proprietary, it appears that the cost goal is within reach.

Recently, a user terminal with a 1 watt (27–31 GHz) GaAs MMIC amplifier using 0.15 μm InGaAs/GaAs psuedomorphic HEMT technology, was reported by Hyundai, Korea.

The business user terminal would be expected to access satellite capacity with higher burst rates and simultaneously serve multiple individuals, for example, at one business location or facility. Because of the business application, service to multiple users, and other factors, the business terminal would be somewhat larger and higher in cost. Planning estimates have suggested a cost goal of about $10 000 for the business terminal. The business Ka-band terminal could use many of the components developed and produced for the private or home use terminal, thereby realizing benefits of a larger production base. To reach the cost goals, application of the traditional learning curve of cost versus cumulative manufactured quantity must be recognized and creatively applied [3].

An example of an multimedia VSAT design which is innovative yet sensitive to cost is under study by KDD. A bi-directional (transmit and receive) multimedia service is envisioned with a 46 cm aperture receiving a 40 Mbps time division multiplex (TDM) waveform transmitted by a 7 meter hub. The return link (from user to hub) would be 128 kbps binary phase shift keying (BPSK) chirped (for low cost) to spread the energy over a 500 kHz bandwidth.

Terminals for systems such as Teledesic that use lower altitude orbits introduce the problem of 'handover' (from one satellite to another) during a session. Achieving low cost terminals would seem to require a single antenna aperture and rapid handover also suggests phased array antennas.

2.3. *TVRO (Television Receive-Only) terminals*

Because of the compelling nature of video, direct-to-user satellite delivered television is possibly the most important medium ever produced for mass communications; and mass communications is achieved only because of the low cost receive-only terminal (TVRO). Television receive-only stations now outnumber all other types of terminals, with highest populations in North America, Europe, and Asia.

Ku-band television receive-only stations are now proliferating in the United States, Europe and Japan. (Some of the factors for this pattern are outlined below.) The typical TVRO antenna is about 46 cm in diameter. A LNA followed by a block frequency downconverter produce an rf signal at a microwave intermediate frequency (IF) suitable for transmission through a coaxial cable. The low noise block converter has been mass produced in the form of a monolithic microwave integrated circuit (MMIC). This device has become the most widely produced microwave component in history. The IF signal is delivered to an indoor unit (usually termed a 'set top box' in digital television applications). The set top box selects the appropriate carrier, processes the signal and converts it to analog form for presentation. Digital television has become economical due to compression algorithms that allow 10 or more television channels per carrier/transponder.


Kyoto, Japan, June 1997

Fig. 3. Satellite television receive-only terminals in Japan.

The technology for producing the TVRO terminals is well established and costs have been driven down by mass production. World totals are shown in Fig. 1.

Distribution of analog television signals (e.g., to network affiliates, cable head-ends and hotels; education systems, sporting or other news events; and for major network program distribution) remains a common use of satellites. The number of terminals for this type of use is again difficult to estimate (but is likely to be on the order of 10 000 in the United States). Within the United States, availability of these downlink signals (at C-band) led to low cost 'back yard' antennas for private use; the number of these is almost 2.0 million, and is decreasing due to the availability of digital TVROs at a fraction of the cost of the larger analog units.

When digital broadcasting was introduced in Japan, the number of digital TVROs purchased reached a million within six months. The antennas are so small that they do not violate cultural concerns for clarity and order, and may be seen today throughout Japan. This is an important observation, because the multimedia home or personal terminal will be of similar size and configuration, and therefore will have no impediment to broad application. Some private TVRO antennas in use in Japan are shown in Fig. 3.

2.4. *Handheld terminals*

The dream of a handheld terminal for satellite communications seemed distant as recently as 1990. But imaginative application of technology developed for use in other contexts produced system designs enabling

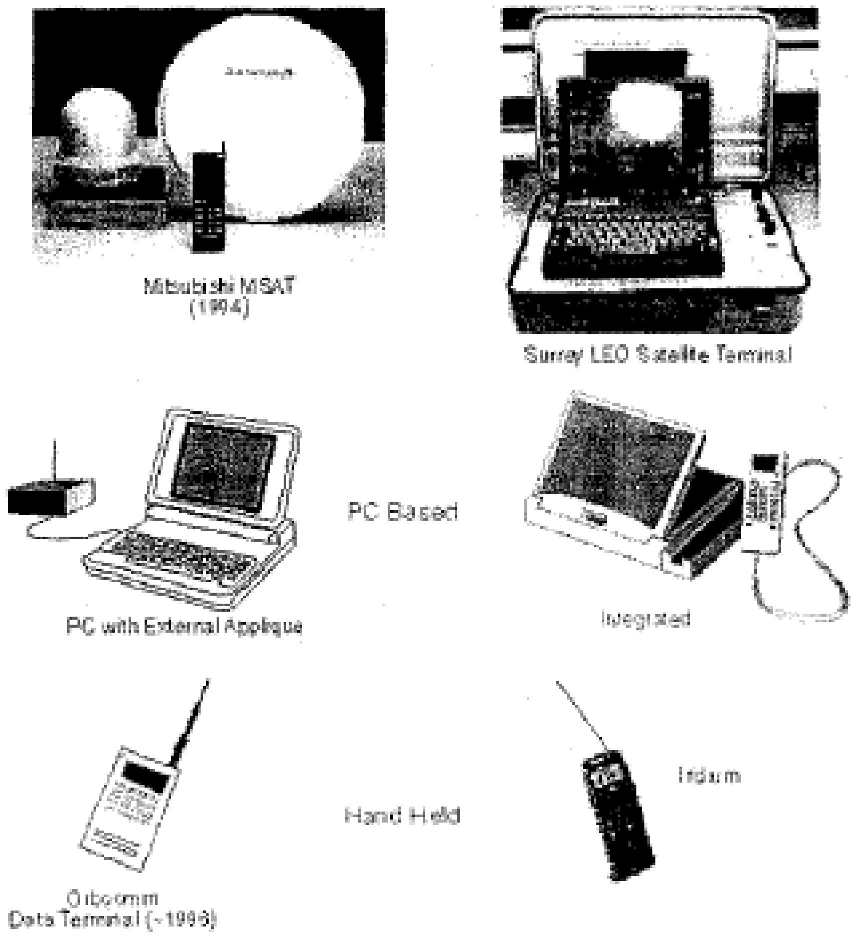


Fig. 4. Handheld and highly portable communications satellite terminals.

hand held voice terminals.[1] Hand held data terminals have also been created for little LEO data systems. Orbcomm terminal designs have been complete for several years. Hand held satellite terminals are not yet in large volume (compared to terrestrial mobile) production.

The hand held terminals designs for voice are being designed and produced for market trials beginning in 1998. Data terminals are not yet in volume production but are available as engineering models from multiple sources. The hand held data and voice terminals are exemplified by data terminals for Orbcomm, and the Motorola Iridium handset, illustrated in Fig. 4.

A small transportable terminal for use with store and forward microsatellites (i.e., typically 50 kg in weight), both produced by the Surrey Satellite Research Center at University of Surrey, UK, is also illustrated. (The store and forward link data rate with the Surrey microsatellites is typically 10 kbps, and about 750 kilobits can be received in a single satellite orbital pass.)

The terminals concepts in the center row of Fig. 4 are based on the ubiquity of personal computers and related technology. These terminal concepts may use a computer as the input/output device (i.e., for composing messages and displaying received messages), becoming a satellite terminal by addition of a small appliqué box, similar to an 'outdoor unit' for a VSAT; or the rf functions may be integrated to produce terminals that resemble laptop computers. At S-band and lower frequencies, it is feasible to integrate a handheld satellite terminal with a handheld, computer-like device or palm-top computer to create an 'information

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[1] Iridium is said to have been suggested by conventional terrestrial cellular technology (satellites provide moving cells to relatively fixed mobile users) and Globalstar combines CDMA cellular telephone technology and high performance phased array components developed for SHF military use. Both systems incorporate other significant innovations as well.

appliance', tailored for a specific information delivery and use. While such instruments have not yet appeared, they may soon emerge in context of cellular or LEO satellites and offer a low-end competitor to more capable, advanced multi-media satellite terminals which use a laptop computer as the input/output device. Some of these terminals incorporate a voice capability and are highly portable but are not considered 'handheld' for purposes of this discussion.

Globalstar handsets are termed user terminals or UTs. Reflecting the multi-mode philosophy, there are 3 types of UT: Globalstar only; Globalstar & GSM; and Globalstar, GSM & AMPS. Qualcomm is designing and building the handsets; Orbitel (owned by Ericsson) will build handsets in the UK in addition to suppliers in Italy and Korea. The CDMA parts are delivered by Qualcomm; the power amplifier chip is made in Japan. Currently the GSM/AMPS parts are joined with a CDMA phone, with no integration except for battery, microphone and headphone. Integration will follow later (functions on single chips, same data rates, etc.). UT software comes from the terrestrial cellular phones applications. As is also true for Iridium, the Globalstar gateway software has taken major large pieces of code from terrestrial base station software.

The Globalstar UT is light and has a deployable, dual quadrifilar helix type antenna that must be held vertically. Doppler effect is compensated for between gateway and satellite. Predictions help the UT to acquire the signal quickly. Call setup is via a random access channel; after a connection has been established, all control information is transmitted via the communications channel, including the power control (update rate, order of seconds). The CDMA handset could benefit from miniature filter technology realizing lower out-of-band emissions and also from a more efficient high power amplifier (HPA). Filters for the out-of-band emission problem are difficult for CDMA, in particular for a higher power automobile unit.

3. Portable and mobile terminals for multimedia & business use

Satellite-based multimedia service for the consumer is an important part of the business plans of many of the Ka-band systems now under construction. This has developed as an important activity since the 1993 study. Research programs like ACTS, Japan's program in highly intelligent communications, Italy's ITALSAT, and the European DIGISAT, ISIS and MMIS projects, demonstrate that the feasibility of satellite-based interactive multimedia services, are laying the necessary groundwork. The development of portable and mobile terminals for these applications should proceed rapidly along an evolutionary path since – except for reducing terminal size and cost – few hardware changes innovations are involved.

3.1. Japanese activities

Mobile multimedia satellite service is an important research area in Japan. Japanese researchers are looking at all aspects of networked multimedia communications, of which satellites and satellite terminals are but one part (Fig. 5). Japanese research includes both direct satellite systems (Fig. 6) and cellular systems supported by satellites (Fig. 7). '

One of the missions of the Japanese ETS-VIII satellite (2002 launch) is to provide Internet services for mobile users. Planned experiments will test e-mail, file transfer, World Wide Web, and videoconferencing between mobile users and network computers. Figure 8 and Table 1 indicate the general concept of the program and indicate some of the parameters, respectively. The terminals will transmit approximately 20 W and operate with 10 m class antennas on the spacecraft.

Multiple access is a key issue in satellite multimedia terminal development since the earth stations cannot hear each other's uplink transmissions and the network cannot rely on the carrier sense multiple access (CSMA) protocols commonly used in terrestrial local area networks (LANs). The ETS-VIII experimental terminals will be able to select both random and reservation ALOHA schemes.

Large Japanese companies like Fujitsu are aware of the commercial possibilities of satellite multimedia delivery and already offer integrated voice, data, and image in their VSAT systems. (These probably will be extended to mobile and portable applications. Fujitsu's 1996 annual report describes the company as aggressively developing its network based multimedia business.)

KDD is developing an ultra small Ku-band USAT antenna targeted for multimedia services, coming to Japan early in 1998. PerfecTV has already introduced digital DBS; DirecPC also has been introduced, but it uses the PSTN for the return path. A bi-directional (all satellite) multimedia service is envisioned with a 46 cm aperture. A 27 MHz transponder will support a 40 Mbps QPSK time division multiplex (TDM) wave form transmitted by a 7 meter hub. The return

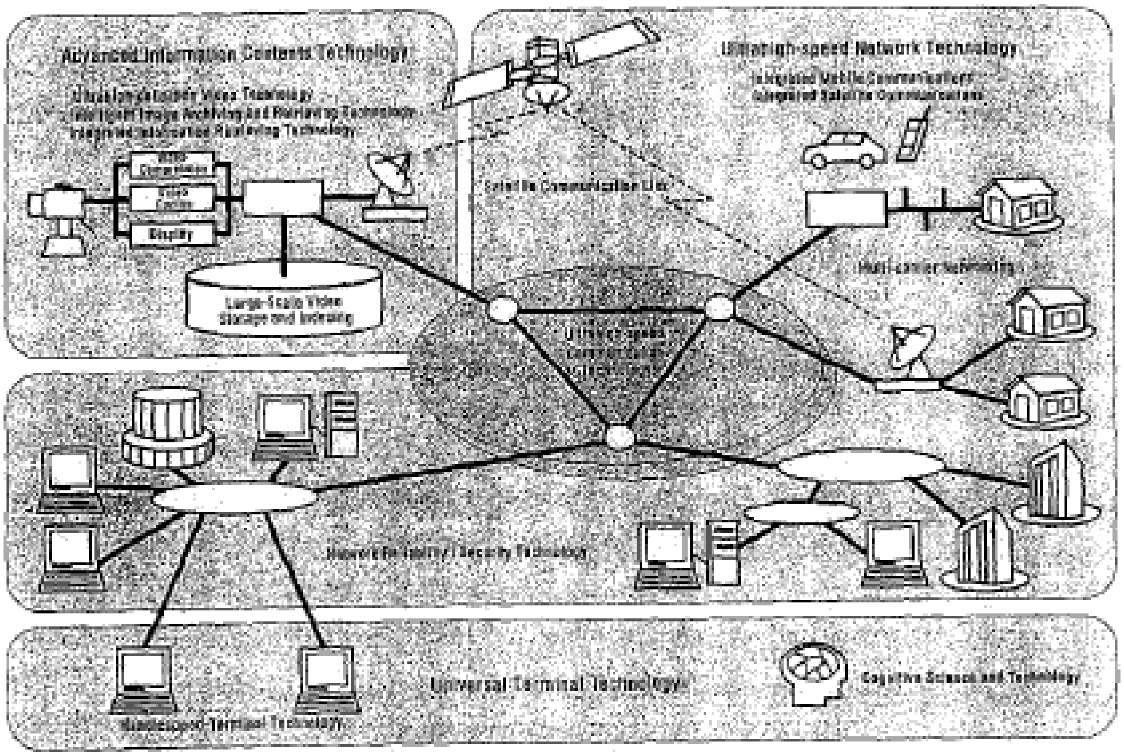

Fig. 5. Concept of a multimedia network (Japan).

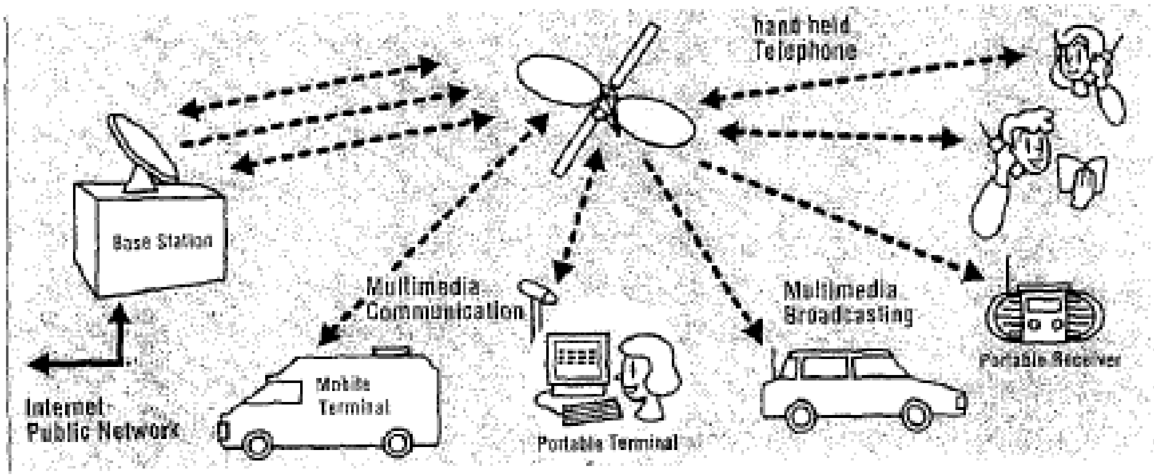

Fig. 6. Concept of a satellite-based multimedia network (Japan).

link (from user to hub) would be 128 kbps, using a chirped binary phase shift keying (BPSK) wave form. The chirp is used to spread the energy over a 500 kHz bandwidth and is sufficient to prevent interference, allowing for a 0.5° pointing error for a home installation, with 3° orbit spacing. A 1 W transmitter will be integral to the outdoor unit, designed for continuous transmission in 20°C air. Use of TDM multiple access is anticipated and will produce a low duty cycle.

3.2. *European activities*

European companies and laboratories are also developing multimedia satellite systems and planning

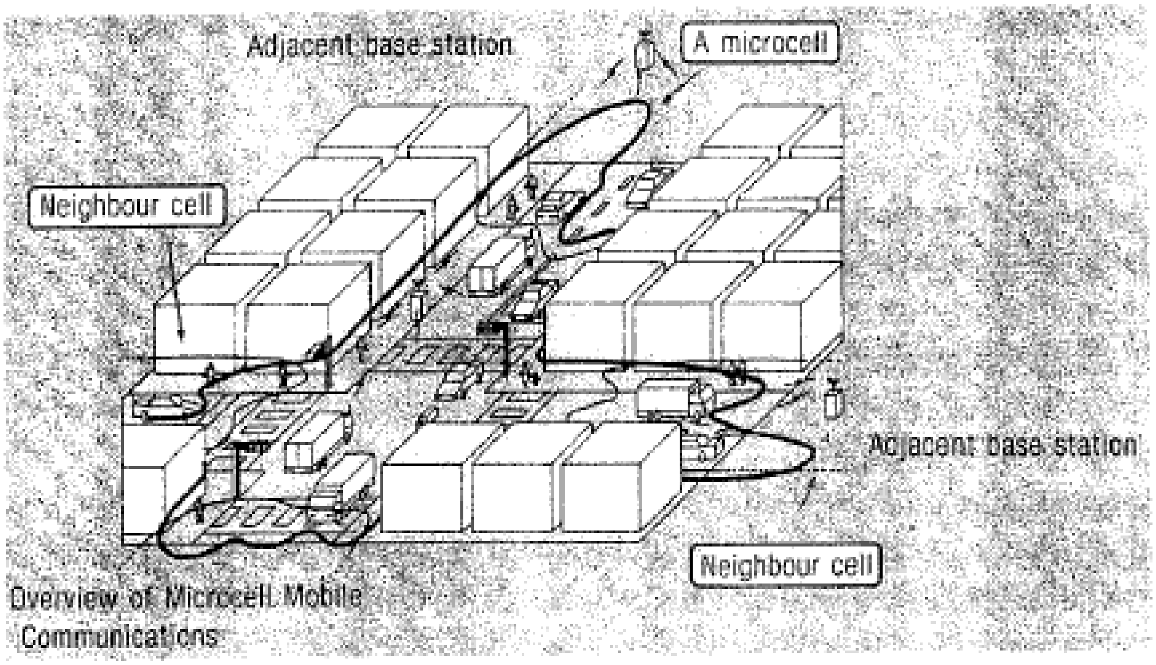

Fig. 7. Concept of a cellular multimedia network supported by satellites (Japan).

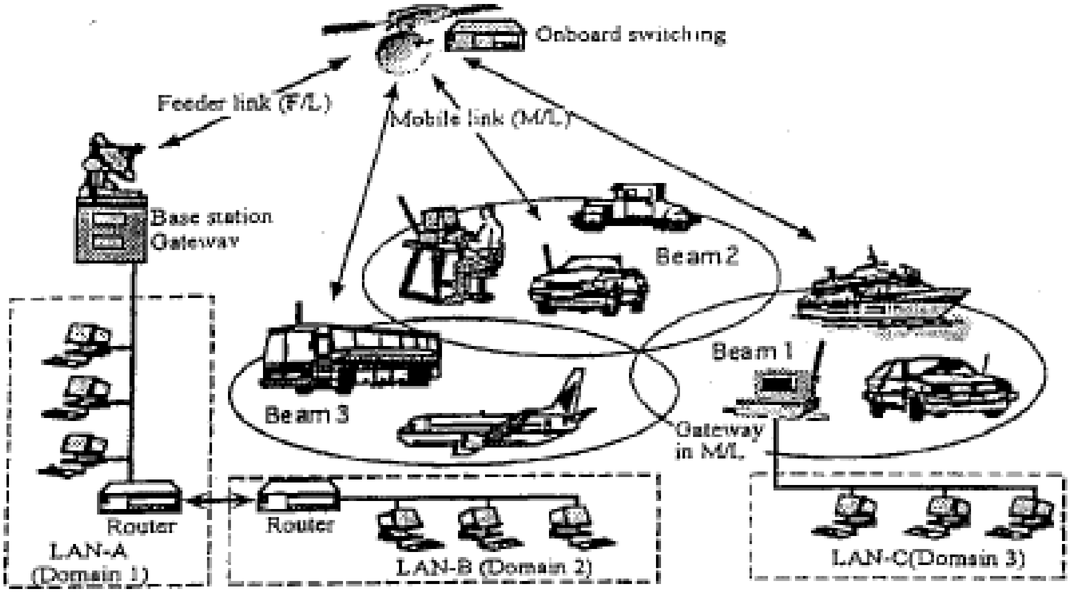

Fig. 8. Planned multimedia experiments with ETS-VIII.

portable and mobile services. The SECOMS/ABATE projects, described to the panel by Alenia Aerospazio, have as their objectives 'to manufacture . . . vehicular land-mobile and aeronautical terminal prototypes . . . using electronically steered array antennas . . . [and] to demonstrate the feasibility of broadband multimedia satellite services . . . for mobile users with flexible data-rate assignment'. SECOMS/ABATE will 'define an advanced satellite system configuration, envisaging portable/mobile terminals to cope with various environments and for individual/collective use'. Figure 9 illustrates the proposed network architecture and indicates some of the anticipated data rates.

Table 1

Link parameters for ETS-VIII mobile multimedia experiments

Modulation	QPSK
Demodulation	Coherent detection
Information rate	512 kbps (forward error correction (FEC) on) or 1024 kbps (FEC off)
Error correction	FEC (convolutional coding ($k = 7$, $R = 1/2$), Viterbi decoding)
	Selective repeat ARQ
Error detection	32 bits CRC error detection
Link access method	Modified slot ALOHA (random access + reservation access)
Collision detection	Announce from satellite
Slot length	8 ms
Frame format	Multi-frame
	Minor frame: 128 ms
	Major frame: 1.024 s
	Super frame: 8.192 s
Switching port	2 feeder links, 2 mobile links
Routing protocol	First phase: bridge (addressing in datalink layer)
	Second phase: TBD
Download function	Download from base station through feeder link
MPU	RAD6000 (10 MHz)
OS	VxWorks

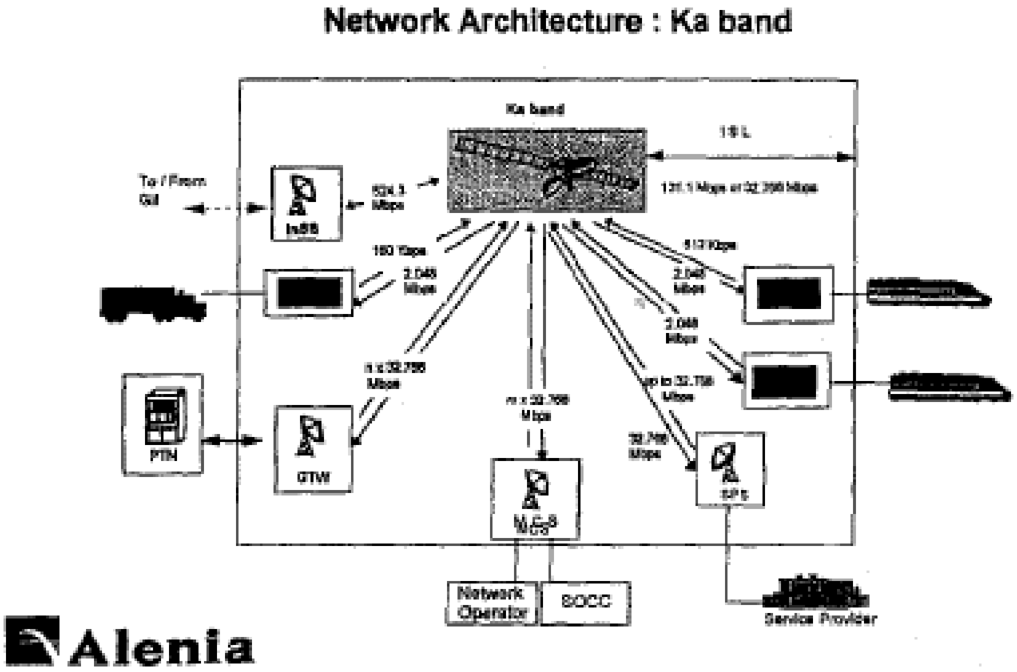

Fig. 9. Proposed European multimedia network architecture from SECOMS/ABATE projects.

4. Airborne and ship borne terminals

Airborne and shipborne terminals have continued to grow in population at an increasing rate. These terminals might be considered an intermediate class between 'personal' (individual, single user) and the more traditional larger FSS terminals not associated with a particular user or group of users. In any case, airborne and shipborne terminals are both important in themselves and possibly as indicators or precursors to the larger market included within the category of mobile systems (MSS).

In Japan, KDD is doing particularly interesting work on array antennas for mobile applications. A low profile is achieved using 2 layers of slightly overlaid patch radiators. The 3 × 3 array performs at both 2.3 and 1.6 GHz, as both transmit and receive, and was tested with ETS-V. The antenna uses a conventional beam-forming network; for more performance, an active phased array would be used. The second-generation model is a single layer with two element sizes on a high dielectric substrate. The axial ratio was not satisfactory, and a third generation model has been constructed. Similar to inverted-F, multiple short pins above each patch allow the sizes to be reduced to almost half; the patches can then be laid out without overlap in groups of four (transmit and receive for each band). There are 18 analog phase shifters (9 elements × 2 frequency bands), digitally controlled, and packaged into a small box. Transmit power is 250 mW per element.

A third array antenna, targeted for ICO and the Japanese Experimental Satellite (ETS-VIII), uses a quadrifilar helix radiating element. The antenna will have 12 elements arranged in a triangular grid pattern (with corner elements missing from the grid). The feed electronics were packaged into four layers (for ease of further evolutionary changes). Diplexers comprise the first layer; LNAs the second layer; an analog beam forming network (BFN) the third layer; and down converters in the fourth layer. A design change is being introduced to substitute a digital beam forming network for the analog BFN. The feed network has one, two or three output ports. The antenna has 16 beam positions (switchable). Use of TDM downlinks might allow beams for two satellites. While ICO will use 6 kb/s links/user, thin route FSS multimedia is anticipated to operate at 64 kb/s, requiring about 10 dB more gain.

Inmarsat maintains a record of commercial aircraft having terminals installed. As of the end of 1997, there were 856 installations. The majority of these are 5 channel units on large aircraft that allow passenger telephone service. Inmarsat type qualifies terminals and there are a number of certified terminal providers.

Inmarsat also maintains records of ship terminal commissions. As of the end of 1997, there were 50 687 Inmarsat shipboard terminals in service. Improved, lower cost technology and competition have each both helped to lower the cost of Inmarsat airborne and shipborne terminals. It is perhaps significant to note that the service provider originally ordered 200 ship terminals on speculation, partly with the intention that a large order would encourage tooling for quantity and other cost saving approaches for terminals. This decision not only made a terminal product available but also held the initial price to $50 000. This is an historical example of a creative exploitation of the cost versus quantity relationship.

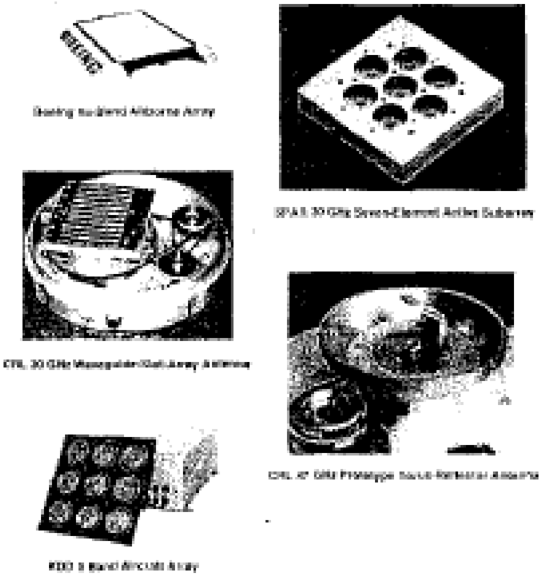

Fig. 10. New aircraft and mobile antenna designs.

The more important development in airborne terminals is the successful production of phased arrays at Ku-band for aircraft, by Boeing. A photograph of the low profile Boeing Ku-band phased array is shown in Fig. 10, which also includes a few examples of other airborne and satellite phased array antennas from around the world. This set is by no means exhaustive. An overlooked aspect of phased array antennas is their use in synthetic aperture radars being flown on satellites. The activity for earth observation is synergistic with communications satellite applications (e.g., requiring manufacture of large numbers of efficient, small, and reliable array elements).

The communications antennas allow reception of DBS where satellite coverage permits (i.e., currently, there is not a lot of coverage over oceans where it might be most useful to airlines). Current systems would suggest two way airborne terminals at Ka-band; however, the cost associated with current technology may slow the spread of such terminals. The alternative is to employ lower gain arrays either made possible by lower altitude systems (e.g., Teledesic) or enabled by still higher effective radiated powers (EIRP) GEO satellites. In any case, development of airborne arrays at Ku- and Ka-band will be an important area of future development.

5. Hubs and gateways

A 'hub' is a large aperture terminal that is used as a central network control of smaller terminals (e.g., VSATs). The hub assigns transmit and receive channels, monitors traffic for billing purposes, relays messages between VSATs (if required) and connects the VSATs to other media. When the other medium is the public telephone system or another satellite system, the hub is functioning as a 'gateway'.

Gateway terminals have been inherently designed into the fabric of nearly all personal/mobile and little LEO data/messaging satellite systems. The rationale for this is to allow country by country connection to the local responsible government post and telegraph (PT&T) authority or independent carrier. The assumption is that calls or messages will likely originate or terminate at telephones, with a mobile terminal at the other end of the link. The gateway therefore provides both a telephone interface and a central point for traffic monitoring for local billing. This rationale also applies when a mobile terminal is at both ends of the link. The possibility of revenue generation also creates globally distributed interest and potential participation in financing the overall system.

Since the Inmarsat consortium has 81 participating countries and INTELSAT has 165 signatories, each personal/mobile system has the potential of about one hundred gateway stations. Since the personal and mobile systems use low and medium orbits, multiple satellites may be in view and each gateway station may have multiple terminals. Many Iridium gateway stations have five antennas. It was determined by analysis that for Globalstar gateway locations, 3.1 antennas were needed on average, so usually four antennas were provided. Gateways are under construction around the world for Iridium, Globalstar and Orbcomm. Gateway technology is no problem, and no major initiatives are needed. Most of the gateways employ US technology.

Multimedia Ka-band systems may employ hubs (e.g., for Intranets) and gateways for enriched connectivity. Although typically regional in geographic focus, these systems have multiple country coverage and the same rationale for gateways as the global systems. Hubs and gateways typically employ ~4 to 10 m antennas. The antennas and all other radio frequency components are available as existing products (feeds, LNAs, HPAs, frequency converters). One distinction is the requirement to track moving satellites for systems using lower orbits. This has not been typical for geostationary satellite systems and places a new mechanical design/reliability requirement on the gateway terminals, which must be ultra-reliable due to the central role they perform in communications. Radar antennas provide some useful experience and technology; and redundant backup or a single spare antenna per gateway will allow high gateway availability.

6. Military terminals

An important recent change of direction in US military satellite communications has been the congressional direction to emphasize the use of commercial systems. Changes in the world situation and evolving defense roles have resulted in review of terminal performance characteristics. A significant investment exists in the form of UHF (300/250 MHz), SHF (8/7 GHz), and EHF (44/20 GHz) military terminals, making a sudden shift to commercial use both difficult and costly. 'Use of commercial systems' would seem to imply use of commercial terminals (L/S, C, Ku-band). In particular, commercial systems can not be viewed as 'in place', since locations of military operations are uncertain and maneuvering of forces requires either transportable or mobile terminals.

For ground terminals, an alternative concept is to provide terminals capable of operation in any of several frequency bands (e.g., C, X, Ku). The operational advantage is the ability to employ multiple satellites in any location due to the high population of commercial satellites. Advanced versions of such 'tri-band' terminals have lower weight, volume and cost than the single band terminals they are to replace. An important development achieved by L3 Communications is an antenna feed capable of operating across the C through Ku-bands without adjustment or change of components. A photograph of an antenna with this feed is shown in Fig. 11.

Introduction of a global broadcast system at Ka-band will result in a need for receive-only terminals for ground, aircraft and ship applications. The quantity of such terminals will depend more on the use of the broadcast channel and consequent organizational levels using the broadcast information. The success of direct broadcast satellite television and low cost receive-only terminals will likely lead ultimately to broad use

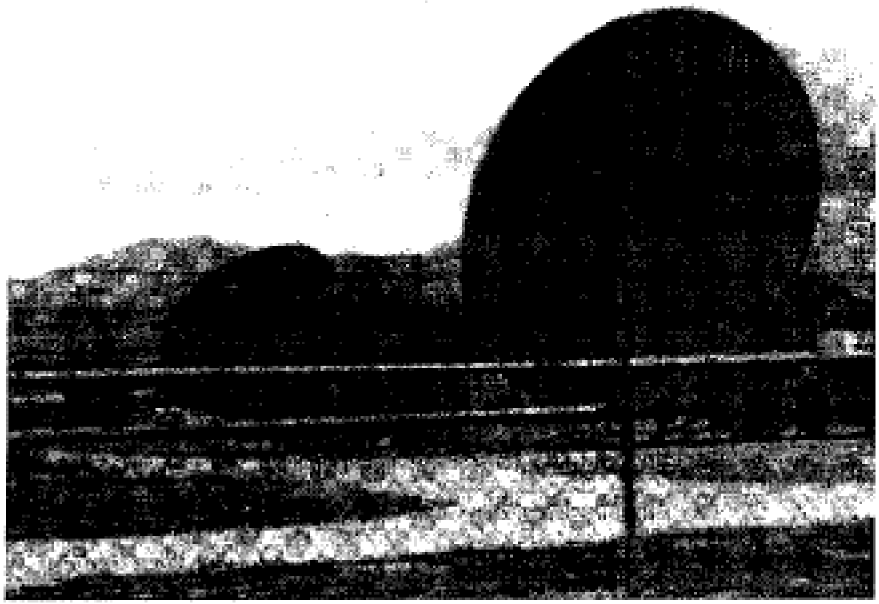

Fig. 11. L3 communications antenna incorporating proprietary very wideband feed.

and a large population of terminals. Plans now call for receive-only terminals; specific information must be requested via other communications systems (i.e., rather than via a direct satellite uplink from the receive terminal).

A need to address satellite replenishment for SHF and severe budget constraints has led to planning studies suggesting the possible future use of Ka-band. A Ka-band system would make possible a two way terminal that might closely resemble the Ka-band multimedia VSAT. Proximity of commercial and military or government Ka-band frequency allocations suggests the possibility of a shared technology and production base, thus offering a promise of cost savings.

Government needs, particularly military applications, require mobile and airborne capability. Presently planned Ka-band commercial systems have two potential problems in this regard, namely coverage and adaptability for such mobile users. The commercial systems are aimed at population centers of highly developed countries, whereas humanitarian and military operations historically have been most often in undeveloped areas, precisely where coverage is not planned. This apparent disconnect between the commercial plans and government needs is discussed in two papers presented at the 1997 Third Ka-band Utilization Conference [4].

A cutting edge issue will be airborne terminals. A variety of considerations point to phased arrays as the appropriate choice but current gain requirements demand large numbers of array elements resulting in high costs. Further evolution of systems to allow lower cost antennas and to facilitate mobile terminals was independently suggested in the two papers at the Third Ka-band Utilization Conference [4].

7. Conclusion

The major challenge for commercial systems is the achievement of low cost of production to encourage rapid market development. This applies to both mobile/personal systems and to multimedia VSATs. In particular at Ka-band, low cost microwave components such as solid state amplifiers (1 to 5 W rf power) have to be developed before market success is likely.

A major challenge is to achieve high performance airborne antennas at reduced cost. Progress in receive arrays for Ku-band GEO systems is encouraging. However, extension to low cost transmit and receive arrays for Ka-band airborne applications needed for both commercial airlines and government/military uses remains a challenge. A similar airborne terminal challenge (high performance/low cost) will exist for LEO/MEO systems.

Since systems design can in principle bundle many combinations of services and data, determining the associated combination or set of terminal features that can both be produced within cost goals and achieve the required market appeal may prove the critical challenge determining the economic success of many systems.

A general challenge to government/military terminals is interoperability with allies. Introduction of the use of commercial bands will not ease the dimensions of this long standing interoperability problem. A specific challenge for military terminals is to provide the required features without extensive redevelopment of commercial products. The advent of consumer oriented satellite communications together with reduced defense budgets greatly diminishes opportunities for technology leadership through innovation for military terminals. Innovation is expected to come for the commercial terminals; however, there will remain military features and requirements that may not be satisfied without targeted or focused development.

Interoperability features of handheld terminals are important. Terminals having several modes, such as one satellite and one terrestrial cellular standard, are expected. But more diverse functionality may be both highly useful and a market differentiator (for handset providers). 'More diverse functionality' refers to the possibility of being able to operate in more than one satellite system and/or more than one cellular system.

The continuing improvement of digital components (reduced feature size, lower voltage operation, processing power, software libraries) due to advances in the computer industry will offer much of the raw material needed for handset innovation and multi-mode functionality. Of course, selection of particular technologies and adaptation and specific development for terminals will be required. Improved and innovative visual displays will suggest changes in services (and increases in link data rates) and again challenge terminal designers to achieve low cost, even with the addition of displays or other media features.

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