

The possibilities for Mobile and Fixed Services up to the 20/30 GHz frequency bands**C.D. Hughes¹, F. Feliciani¹, J. Spiller²**

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INTRODUCTION

Satellite Communications and broadcasting is presently in a period of considerable change. In the fixed service there is strong competition from terrestrial fibre optic systems which have virtually arrested the growth of the traditional satellite market for long distance high capacity communications.

The satellite has however made considerable progress in areas where it has unique advantages; for example, in point to multi-point (broadcasting), multipoint to point (data collection) and generally in small terminal system applications where flexibility of deployment coupled with ease of installation are of importance.

In the mobile service, in addition to the already established geostationary systems, there are numerous proposals for HEO, MEO and LEO systems. There are also several new frequency allocations as a result of the WARC 92 to be taken into account. At one extreme there are researchers working on Ka band 20/30 GHz mobile systems and there are other groups who foresee no future above the L-band frequency allocations.

Amongst all these inputs it is difficult to see the direction in which development activities both for satellites and for earth segment should be focused. However, as an aid to understanding, this paper seeks to find some underlying relationships and to clarify some of the variables.

THE IMPACT OF USER REQUIREMENTS

One possible starting point in trying to gain a better insight into the basic relationships which affect the economics of various satellite system designs is to consider the user requirements. In the formative days of the satellite communications industry this was not really of the highest importance because the systems were organised and operated by large carriers and PTT administrations and the end user was not directly involved. A high and growing proportion of traffic is now carried by small terminal systems. Satellites communications earth stations are operated directly from user premises and in the case of mobile systems from the users vehicles and ultimately his person.

The size of the earth station antenna is now a vitally important element in user acceptability. Large antennas are unsightly and

difficult to install and they are a definite disincentive to the use of satellite communications. For the fixed service the user can probably accept earth stations having an equivalent diameter of around 1.5 metres. For the mobile service a good starting point is probably an equivalent diameter of 15 cm.

Another important factor for the user is the power level of the earth station. Stations which consume Kilowatts of power and require large and failure prone tubed amplifiers are unlikely to be popular with the user community. For the fixed service this means that solid state power amplifiers are needed and depending on the frequency this places a limit on the radio frequency (RF) power which can be applied to the antenna. For the mobile service the RF power output is constrained by mobility and human safety considerations.

Fixed Service Link Budget

For the satellite up-path the most important parameter is the RF power available per bit to feed the earth station antenna. The remaining variables do not change dramatically from one system to another. The satellite receive noise temperature is heavily influenced by the temperature of the earth and the satellite antenna size and gain are determined by the up-path coverage requirement from the earth surface.

Figure 1 illustrates the up-path link budget situation for the fixed service with the following assumptions:

- earth station equivalent diameter - 1.5 m
- satellite system temperature - 30 dBK
- propagation margin - 6 dB
- modulation BPSK/QPSK
- Eb/No required (uplink only) - 10 dB

This curve is independent of frequency and can therefore be used as a general guide to choose the approximate up-path parameters applicable to a given system. It also applies in the case of multi-beam systems where the beamwidth of each beam is shown on the X-axis.

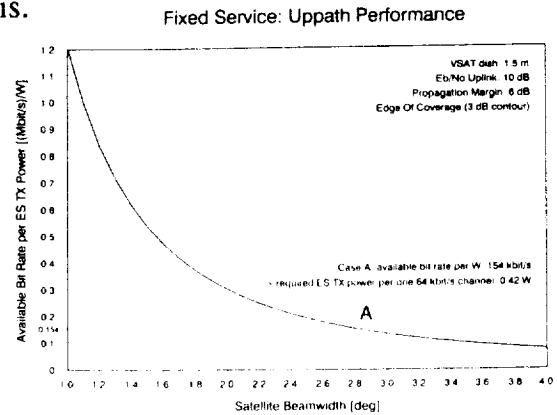


Figure 1: uplink situation (fixed service satellite system)

The same techniques can be used in the downlink which leads to the curve shown in figure 2. This time the critical parameter is satellite RF power allocation per Mbit/s of required downlink capacity.

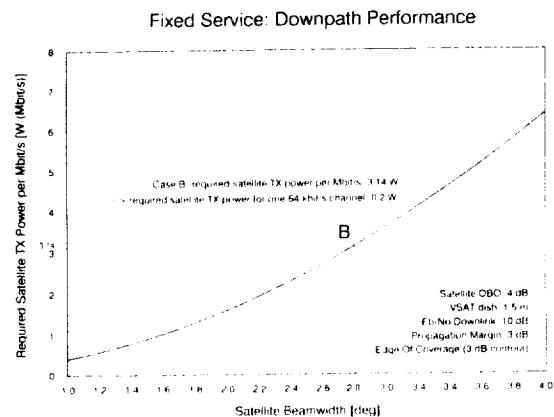


Figure 2. Downlink situation (fixed service satellite system)

Mobile Service Link Budget

If, as previously discussed, the user terminal equivalent antenna diameter is 15 cm both the uppath and the downpath situations

are quite different from the fixed service case. In the mobile case, the antenna diameter of the earth station has gone down by a factor of ten from 1.5 to 15 cm. This represents a loss to the link budget of 100 to 1 or 20 dB. Additionally, an allowance of about 10 dB must be made to ameliorate the effects of shadowing due to trees, buildings, etc. This margin can partially overlap the propagation margin since the joint probability of rain and shadowing is less than the sum of the two. Nevertheless an additional margin with respect to the fixed service case of 7 dB would seem to be necessary.

Thus the overall disadvantage with respect to the equivalent fixed service situation is approximately: 27 dB. Part of this can be regained by the use of bandwidth compression techniques. In the case of telephony, for example, a reduction of the required bit rate for a channel from 64 kbit/s to 4.8 kbit/s (vocoded speech) can be assumed. This is equivalent to 11.3 dB. In summary:

smaller antenna	20.0 dB
additional shadowing margin	7.0 dB
bandwidth compression (telephony)	<u>-11.3 dB</u>
net mobile disadvantage	15.7 dB

This shortfall has to be found in the satellite by a combination of narrower antenna beams to provide more satellite antenna gain and in particular by the provision of a much higher power density in the satellite for the downlink.

The uplink performance is doubly restricted due to the small size of the earth station antenna and the low power of the earth station amplifier.

The equivalent curves to figures 1 & 2 for the up and downlink situation in the mobile case are shown superimposed in figure 3.

It will be noted that whereas the power required in the satellite for the fixed service could be expressed in Watts/(mbit/s), for the mobile service the density is expressed in Watts/(kbit/s). This reflects the disadvantage

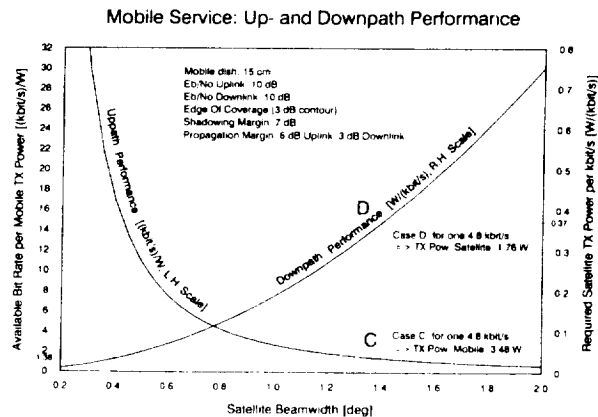


Figure 3. Uplink and downlink (mobile service satellite system)

of approaching one hundred to one experienced by the mobile system with respect to the fixed service system. Nearly all of this disadvantage has to be compensated for in the satellite power output. For a typical satellite the most significant mass elements are the output stages of the payload and the power generation subsystem (solar panels power conditioning etc.). Hence, irrespective of the frequency band employed, as a general rule satellites for the mobile system will always be substantially heavier for a given capacity than the fixed service equivalent. This of course is reflected in the cost and ultimately in the price of the calls to the consumer.

The case of a geostationary satellite has been taken in the examples but it is interesting to note that reducing the altitude of the satellite (the MEO and LEO orbits) brings no improvement in the power density requirement, if the same area of earth is to be illuminated.

Individual link budgets for point A, B, C and D respectively in figures 1, 2 and 3 are given in table 1. All the non variable parameters assumed in the curves are thereby defined.

For the up path link budgets the effect of propagation margins would require the use of power control to avoid overload in clear air conditions. For the purposes of these calculations such control is assumed to exist.

THE IMPACT OF FREQUENCY BAND

The curves presented in the previous section are independent of frequency. However, there are a number of factors which do affect the choice of frequency band.

Available spectrum

The available spectrum for the mobile service in the L-band is limited to a few tens of megahertz. Even with considerable re-use of frequencies this is somewhat limited and there is a case for targeting the much larger bandwidths available at Ku band and Ka band for some mobile services.

The higher frequencies also have some attractions for the mobile service because it may be possible, with appropriate processing, to operate these services using existing satellite capacity in parallel to the existing fixed service and broadcast transmissions. This has obvious advantages since it permits mobile systems to be established on a marginal cost basis thus avoiding the high initial investments necessary for a dedicated mobile system. Such systems are already in operation in a limited way for low bandwidth data exchange in the Ku band, both in North America and Europe.

However, it is difficult to operate small terminal or mobile systems in an environment

where large earth stations are already in use. The required satellite gain settings and the interference environment are normally quite different. However, in the Ka band it would be less difficult to operate a wide range of services e.g. broadcast, fixed service, mobile since there are no existing systems and the parameters could be adjusted to enable small terminal systems to be used.

Propagation effects

It is well known that the Ku band and particularly Ka band suffer from atmospheric attenuation due to rainfall. This has the effect of increasing the required link margins and/or increasing the unavailability of the system to the user. There is now a great deal of experience in using Ku band throughout the World. However, experience with Ka band for satellite communications and broadcasting is more limited.

The Olympus satellite has two transponders in the 20/30 GHz frequency band and has provided the opportunity for European and Canadian organisations to gain experience in these frequencies over a period of four years. In general the experience has been very positive and it has been possible to use the band extensively for broadcasting, VSAT systems, video conference and news-gathering on a regular basis with good results without the use of excessive propagation margins. This anecdotal information has been supplemented by extensive propagation beacon measurements of a more scientific nature.

The results indicate that 20/30 GHz can be used successfully for all types of service provided the availability requirements of the user are modest.

The band appears to be unsuitable for high availability trunk connections, unless special fade countermeasures are employed, but is very suitable for small terminal user oriented communications where availabilities of typically 99.5% are acceptable. Hence low cost is an important element to be traded against availability. Figure 4 shows propagation statistics derived for 650 geographically separated locations within Europe and based on a propagation model which has been verified using Olympus data. It will be seen that with uppath and downpath margins of 6 dB and 3 dB respectively almost 100% of sites can be served with an unavailability of 1% and 50% of sites achieved 0.5% unavailability. With margins of 8 dB and 4 dB, an unavailability of 5% can be achieved in all but the very worst locations.

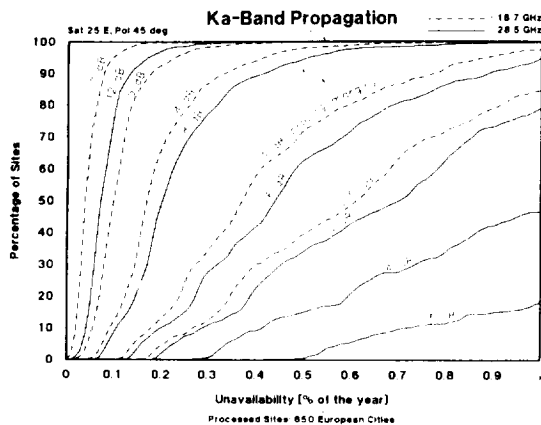


Figure 4

Doppler effects

At high centre frequencies the doppler shift caused by the movement of vehicles or people is proportionally higher. This means that special measures have to be taken in the receivers and transmitters to overcome the frequency offsets. These problems have already been successfully addressed in experimental designs.

Earth station beamwidth

Clearly, the beamwidth of the earth station antennas becomes proportionally narrower as the frequency is increased. Tracking antennas therefore become necessary. This is a severe disadvantage in increasing the complexity of the mobile terminal. On the other hand the narrower beamwidth involved progressively limit the interference to and from adjacent satellites.

Satellite mass

If we select an operating point on the power/coverage curves and look at the variation of satellite mass as the frequency goes from L-band to Ka-band one finds that to first approximation the mass remains constant. This, at first sight, surprising results was obtained by taking several satellite configurations and applying the known mass of the various payload and power system elements for the various frequencies. The outcome is mainly due to the interaction between two factors. As the frequency increases the antenna size for a given coverage reduces as well as the size of the microwave components thus reducing the mass of the satellite. However the lower power efficiency of the HPA and the losses in the microwave components result in an increasing power demand by the payload and an increase in mass of the satellite. There is a small (10%) but noticeable step increase in the mass at Ku and Ka-band due to the change from SSPAs to TWTAs in the HPA.

The above results assume that the number of beams on the satellite is constant. In a practical system as the frequency increases the link margins need to be increased to compensate for fade conditions, this can either be accomplished by increasing the power of the mobile terminal or by increasing the gain of

the satellite. If we select to increase the gain of the satellite the antenna beam size will go down and to keep the same coverage we will have to increase the number of beams to compensate. With a hand held system we do not have the option of increasing the terminal power because of the safety aspects. This reduction of beam size and the consequent reduction in power does have a mass advantage as the frequency is increased even though the number of beams is increased. The mass saving at Ka-band is about 5%.

Thus there is little variation in satellite mass as the frequency changes in a mobile system. However the increase in number of beams significantly increases the complexity of the payload hardware and hence the cost. This together with the general increase in cost of gain at higher frequencies will tend to favour the lower frequencies from the satellite viewpoint even though mass is not an important factor.

CONCLUSIONS

It is concluded that a mobile system tends to be intrinsically much more expensive than a fixed service system. This is because the satellite power and mass has to be greatly increased to satisfy the need to reduce earth station diameters. The additional satellite mass per unit of use is reflected in the investment and running costs of the system.

The calculations made are based on a set of assumptions which do not change greatly with the type of system envisaged. They therefore apply as a first order to any geostationary system single or multibeam. However, they also apply to low earth orbit systems when equal area coverage on the ground is required.

From a system point of view there are no intrinsic advantages or disadvantages in the choice of frequency band for mobile or fixed services. However, there are some factors which will affect the choice of a particular frequency band for a particular system. These are:

- higher unavailability with increase in frequency due to propagation conditions;
- more complexity at higher frequencies due to the need for tracking ground antennas and better doppler compensation;
- more spectrum available in the higher frequency bands;
- possibilities to operate mixed services broadcast, fixed service, mobile with consequent improvement in the spread of risk and cost;
- better interference characteristics for higher frequency systems;

From the satellite point of view, in theory, the mass of the satellite payload should decrease with frequency due to smaller and lighter components. However, the technology tends to be more advanced and mature at the lower frequencies and it is estimated that satellites for the mobile service at Ku-band and Ka-band will be considerably more expensive for some time than the lower frequency equivalents. If a high availability service is required at the higher frequencies the additional propagation margins necessary will impact heavily on the number of beams required for a given coverage and thereby on the cost and complexity of the satellite.

In general one can envisage that the L-Band frequency allocations will tend to attract the high availability but relatively expensive mobile systems. The higher frequencies and particularly the 20/30 GHz Ka band allocations can absorb small terminal systems in the