

## New Challenges in Propagation Research in the U.S.

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### Introduction

Earth/space propagation research in the U.S. is tied to new developments in satellite communications. In spite of the fiber optics competition for trunked point-to-point communications, a host of emerging services are discovering the great potential of satellites for wireless communications. The application of satellites for radio communications appears to grow with a rapid pace in the areas of thin-route and mobile/personal communications.

An important factor influencing the future of satellite communications is the congestion of the spectral slots at Ku- and lower bands. This heavy usage of the spectrum gives rise to conflicts among the users and consequently forces regulatory organizations to relocate frequency assignments, a decision that, for obvious reasons, is unpopular with the relocated service. Because of this frequency shortage, frequencies in Ka- and higher spectral bands are currently viewed as good candidates for Earth/space communications in the future.

Therefore, new challenges in propagation research in the U.S. include the characterization of mobile/personal links and the investigation of higher bands for satellite communications. Figure 1 depicts the above radiowave propagation scenarios. This paper will briefly review the plans and the challenges of the propagation research in the U.S.

### Mobile and Personal Applications

The use of satellites for mobile communications is not a new idea. This application was explored by NASA's Mobile Satellite Experiment (MSAT-X) at the Jet Propulsion Laboratory during the 1980s. It was soon realized that a good understanding of the channel characteristics is fundamental to the planning of mobile satellite

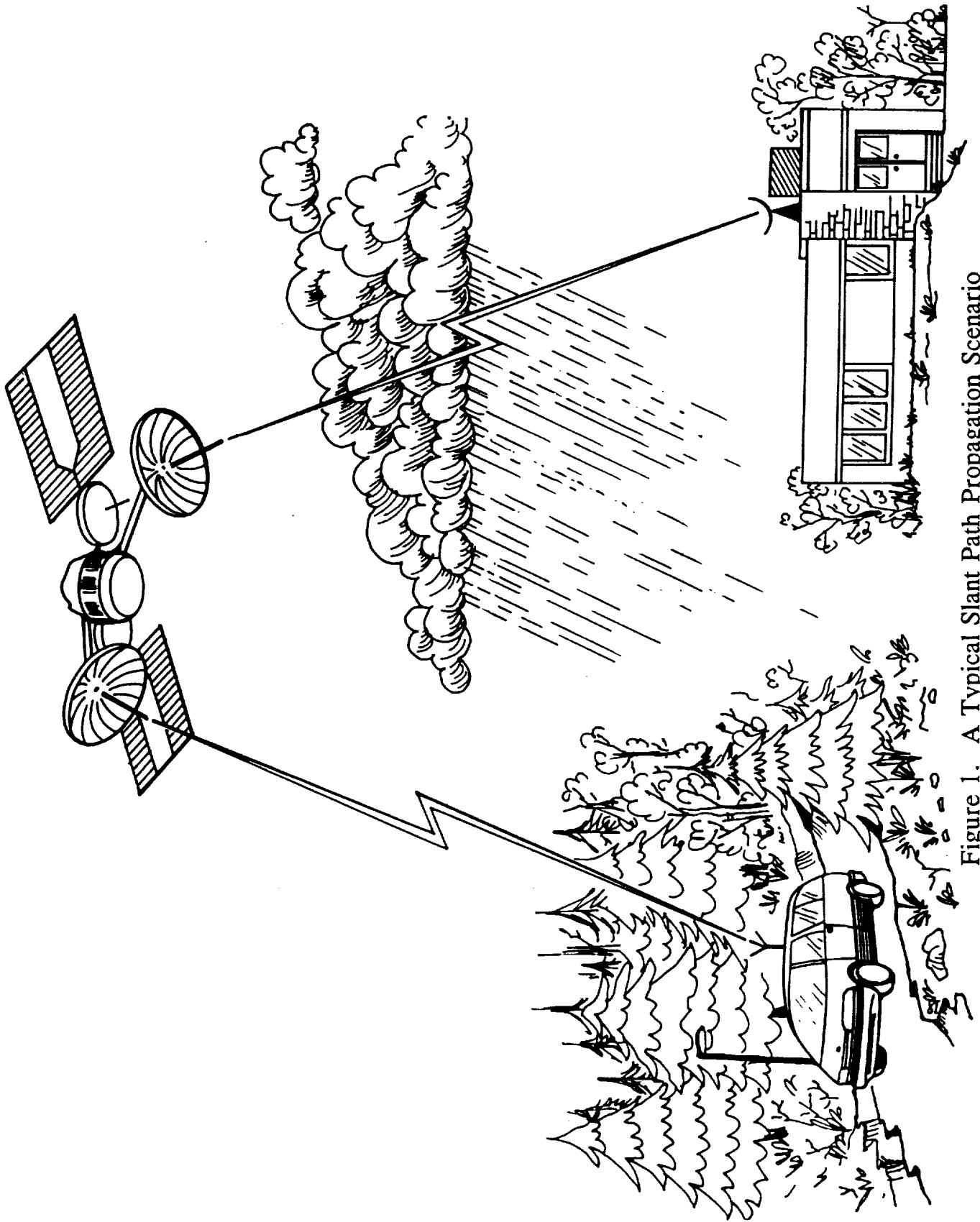


Figure 1. A Typical Slant Path Propagation Scenario

systems. To support the MSAT-X and the emerging mobile satellite technologies, the NASA Propagation Program funded a number of studies to examine the propagation effects of land mobile satellite channels. In addition to analytical work, these efforts included a considerable number of field measurements. In the early years of the endeavor, data were collected using simulated space platforms, such as balloons and helicopters, and in the later years, satellite transmissions were used. The mobile experiments in the U.S. were conducted primarily at UHF and L-bands, and they mostly employed omnidirectional ground antennas. The assumed satellite orbit for studies conducted in the U.S. was geostationary.

It is worth noting that in parallel with NASA's efforts, propagation researchers in other countries also investigated the vagaries of the mobile satellite channel. Notable efforts took place in Canada, Europe, and Japan. Some of these investigations also included aeronautical and maritime mobile satellite links. A compendium of results for land mobile satellite systems can be found in [1], and two CCIR recommendations address propagation in aeronautical and maritime mobile satellite systems [2].

Three recent events have influenced the future of mobile/personal applications.

First, in the 1980s Voice of America recognized the value of satellites in direct radio broadcasting to augment the less reliable shortwave broadcasting [3]. And more recently, the commercial use of DBS-R has attracted much attention [4].

Second, many potential service providers have lately considered the use of satellites for personal communications. Much attention is now being given to LEO as well as GEO satellites.

Third, WARC '92 deliberated mobile/personal applications and opened new regions of the spectrum for them. Although the L- and S-bands presently are the most popular spectral slots, allocation as low as 150 MHz and as high as 30 GHz exist for mobile/personal applications, and most of these frequencies are likely to be used sometime in the future.

The task that propagation researchers are faced with is the characterization of a vast region of the spectrum for mobile/personal links. This assignment is particularly challenging because the mobile

channel demonstrates a nonstationary behavior. Note that mobile/personal receivers may operate in a variety of propagation environments, including reception with or without a clear view -- tree shadowing, blockage, etc. In addition to the above effects, the Doppler-induced dynamics of the signal should also be taken into account.

Currently, data availability is limited to a few selected frequencies with only a limited number of physical and environmental attributes; therefore, future efforts should concentrate on expanding the existing propagation data base to all the bands of interest and include a broader selection of environmental parameters. It is also important that a diversity of satellite orbits, i.e., GEO, LEO, and HEO, be considered in the future studies. The following is a partial list of topics in propagation research which need to be addressed:

1. Conduct propagation measurements into buildings to determine the spatial, spectral, and temporal signal structure for indoor reception.
2. Perform mobile measurements in urban, suburban, and rural environments to derive statistical information, determine model parameters, and obtain data for channel simulation. Measurements through trees must receive much attention.
3. Make stationary and mobile measurements of the delay spread to model the wideband behavior of mobile/personal channels. Sites in city centers and mountainous areas are of special interest.

In addition to the above items, land mobile satellite service providers need detailed statistics on regions of interest to them. However, the collection of detailed information on all the regions of interest will be prohibitively expensive. A good compromise is presented in Item 4 below:

4. Optical blockage and shadowing measurements can be made to provide statistics on a given environment, for example, a given region, a particular highway, etc. It has been shown that optically based sensing systems can predict radio propagation impairments resulting from signal blockage and shadowing [5].
5. Develop service contour maps depending on frequency, orbit, land environment, coverage area, etc.

6. Develop a systematic method for evaluating ITU allotted spectral slots for different applications.
7. To enhance system performance, propagation effects should be mitigated or reduced. Examples are adaptive coding and power control, and smart antennas that can adapt their performance to match the propagation characteristics of the channel (multipath reception).
8. For applications near equatorial regions information is needed on the morphology of ionospheric scintillation at low latitudes, particularly as it affects L through C bands. Examples of services needing this type of information include direct broadcasting to low-latitude countries and aeronautical communications for oceanic flights.

The above studies should also consider the effect of polarization and antenna type on propagation.

In the future, the designers of mobile/personal satellite-based networks are likely to employ simulation schemes for system design and evaluation applications. Therefore, propagation data and models are needed to develop simulation tools. For such applications, time series data or data generated locally using known signal statistics can be used. Future propagation research should support the development of simulation tools.

### Rain and Cloud Effects

Most rain attenuation prediction procedures depend on rain climate models. The available climate models are now about 15 years old, have not been updated in a consistent way to incorporate new observations, and are not dependent on measurable parameters such as annual and monthly rain accumulation, number of days with rain, synoptic conditions to be associated with rain, etc. Once the relationship between rain attenuation model and measurable climatological data is known, maps of the latter can be used to generate maps of the expected attenuation to be exceeded for a given fraction of time on a specific type of path such as from a mobile vehicle to a geostationary satellite. Future propagation research should include a revision of current rain climate models. Furthermore, rain-rate distribution models should be expanded to

represent seasonal behavior of the rain process. The annual/worst-month distribution relationships depend on the seasonality of the process, as do any models designed to explain the variability of the process.

Because most of the available data have been, or will be, used to provide the parameters for model distributions, more samples of the rain rate distributions for locations where observations have been made and for new locations are needed to provide an independent set to test the models.

An important component of most rain attenuation models is the rain height. For many applications the assumption of a fixed rain height is not realistic; therefore statistics on the variation of rain height with day, season, time of day, location within a storm, etc., are needed. For applications such as aeronautical mobile, the stochastic approach to rain height modeling is imperative. It is also important for receiver terminals in the mountains.

Some rain attenuation models depend on the expected correlation between rain rates at different locations along a path. For such applications an improved model for the correlation structure of rain rate can be useful.

By ignoring the microstructure of rain, the available models give rise to errors in signal attenuation prediction and discrepancies in frequency scaling. These problems become more intense for frequencies above about 17 GHz because of the sensitivity of these frequencies to changes in the drop size distribution at the smaller drop sizes. A basic problem lies in the difficulty of making reasonable drop size distribution measurements. Employing measurements at the higher frequencies, i.e., the 90- and 120-GHz windows, simultaneously with measurements at lower frequencies may unravel this problem. The microstructure problem is one that affects our ability to do "frequency scaling," an important component of the uplink power control problem.

Although the influence of clouds can be ignored for the lower frequencies, their effect is important at higher frequencies. The only simple measurement tools available for cloud sensing are multi-frequency radiometers similar to the ones NOAA operates in Boulder, Colorado. Since radiometers cannot determine the atmospheric liquid water versus distance, data from other remote sensing

measurements may need to be combined with radiometric data for cloud modeling. For propagation modeling this is virgin territory with no adequate models and very little data.

### Characterization of the Spectral Bands above about 17 GHz

The congestion of the spectrum for radio communications will inevitably push some services to bands above about 17 GHz. Radiowave propagation at frequencies above 17 GHz is plagued with rain-induced signal attenuation, a factor that for small probability levels can be prohibitive. Therefore, services that require a low to moderate degree of link availability are likely to be attracted to frequencies above 17 GHz sooner than those demanding a very small probability of outage. The aeronautical mobile satellite service can use the Ka-band to its advantage considering that the cruising altitudes of most flights are high enough to either eliminate or considerably reduce the rain attenuation problem. Links in parts of the world with a low annual rainfall can use frequencies above about 17 GHz without significantly compromising link availability. For example, feeder links of mobile satellite systems can be placed in the relatively dry regions of the country to minimize rain attenuation at frequencies above about 17 GHz.

Link availability can be improved via the use of some form of fade mitigation technology. Hence, if tools to offset rain-induced effects are employed, the Ka-band can be used for services that require a moderate degree of link availability but cannot afford a large power margin. Lately, the VSAT industry is showing much interest in the Ka-band. A low margin VSAT can transmit in the Ka-band by either reducing its demand on link availability or employing a fade mitigation technique.

To accommodate low margin systems, future propagation research in the U.S. includes a measurement campaign using NASA's Advanced Communications Technology Satellite (ACTS). An experimental spacecraft, ACTS provides transponders and propagation beacons at 20- and 30-GHz bands. ACTS will also be used for Ka-band mobile/personal experiments. Plans for future research at the Ka-band call for the expansion of the current knowledge on Ka-band propagation with a focus on the following efforts:

- Develop attenuation prediction models for atmosphere-induced effects with attention to high-occurrence, low-attenuation factors, such as light rain, clouds, and fog.
- Refine the existing climatological maps.
- Develop fade mitigation tools.
- Develop a model for large-scale diversity.
- Provide a means of frequency scaling.
- Investigate propagation characteristics of ground and aeronautical mobile channels.
- Develop models for predicting impaired operation and outage duration statistics and the mean time between outages or impairments during a rain event.

The measurement phase of the ACTS campaign is likely to last four years with a total campaign period of five years, 1993 to 1998. Several sites, all equipped with dual frequency beacon receivers and radiometers, will collect data. Considering the complexity of the campaign, much thought has been given to data archiving logistics. It appears that the community will be served best if data archiving and dissemination takes place by a single organization, known as the ACTS Propagation Data Center. Table 1 shows the ACTS propagation measurement sites.

Table 1. Sites for ACTS Propagation Terminals

LOCATION	CCIR Rain Zone	LATITUDE (NORTH) Deg	LONGITUDE (WEST) Deg	AZIMUTH from North Deg	PATH EL Deg	SLANT RANGE Km
Vancouver, BC	D	49	123	150	30	38777
Ft. Collins, CO	E	40	105	173	43	37654
Fairbanks, AK	C	65	148	129	9	40905
Clarksburg, MD	K	39	077	214	39	37971
Las Cruces, NM	M/E	32	107	168	51	37075
Norman, OK	M	35	097	184	49	37242
Tampa, FL	N	28	082	214	52	37060
Montreal, PB	K	45	074	215	31	38583
Montreal, PB	K	46	075	214	31	38582



Since the ultimate goal is to provide design tools for system engineers, the ACTS campaign emphasizes interaction between the experimenters and industry. A forum known as the ACTS Propagation Studies Workshop, formed in 1990, brings together on an annual basis experts from industry, academia, and elsewhere to develop plans for the ACTS propagation campaign.

### Regulatory Issues

The increased use of satellites by today's emerging services will result in new demands for the already scarce resource of the radiowave spectrum. These demands will inevitably result in a more aggressive approach toward revising existing allocations and generating new ones by the ITU. Therefore, regulatory bodies around the world will be in more need of propagation data than before. Hence, propagation research in the U.S. should continue the support of regulatory organizations with an emphasis given to

- Active participation in the CCIR efforts, particularly Study Group 5.
- Support of the ITU in providing spectrum for services which employ satellites for communications.
- Cooperation with other regulatory organizations, such as the NTIA, FCC, Space Frequency Coordination Group (SFCG), Consultative Committee on Space Data Systems (CCSDS), etc.

CCIR Study Group 5 activities entail mainly the development of recommendations for predicting propagation anomalies in communications systems. Many CCIR recommendations can be expanded to better serve system and design engineers. In particular, recommendations dealing with propagation in mobile satellite channels (Rec. 680, 681, and 682 [2]), can greatly benefit from propagation research in the U.S. and elsewhere. For example, those recommendations will be enhanced by providing prediction models for signal attenuation, depolarization, and delay spread at all bands of interest with the elevation angle and the antenna type as parameters.

The inclusion of environmental descriptors in a model for mobile/personal applications is an important factor for the successful use of a prediction tool by system engineers. Examples are the

terrain type in land applications, the state of the sea surface in maritime applications, and the cruising altitude in aeronautical applications. Therefore, CCIR recommendations should be expanded to include models that accurately predict the propagation phenomena for the application of interest at the coverage of interest. Future efforts should include LEO and HEO configurations in addition to the GEO systems.

To predict slant path rain attenuation, CCIR provides prediction models and rain climate maps. The CCIR rain climate maps are in need of improvement; for example, the map for the U.S. places New Mexico, with its arid climate, in the same rain climate region as South Carolina, which has subtropical weather. Clearly future propagation research should correct such discrepancies.

Microclimatology is an important factor in the design and planning of fixed and broadcast services. CCIR models generally ignore this effect and hence give rise to prediction inaccuracies. This topic needs to be addressed by propagation researchers and the resulting data should be provided to CCIR.

#### Data Dissemination and Representation

The sophisticated satellite networks of the present day require automated techniques for link calculation and planning. Propagation prediction tools should be presented to the system engineer in an easy to use fashion. It is desirable that data and models be incorporated with computerized link calculation programs to save time and prevent user frustration. Therefore, the propagation community should provide engineers with user-friendly propagation software that can be easily implemented on popular personal computer systems and readily interfaced to the user's design control tables.

Simulation techniques are playing an increasingly important role in the planning, design validation, and implementation of communication systems. Since the collection of propagation data is often a time consuming effort, an alternate approach may be needed to meet the propagation needs of a system under design. In such a case, simulation can be an attractive alternative, assuming that adequate prior data can be applied to the system under consideration. Therefore, schemes to simulate propagation effects should be developed and provided to system designers. Again, to

enjoy widespread acceptance a simulation tool should use modern software technology and run on a personal computer.

Handbooks are useful tools for educational and system design purposes. In the U.S., NASA has published and maintains two handbooks on slant path propagation effects. NASA handbooks have been used by U.S. industry for many years. Currently CCIR Study Group 5 is also working on a handbook to complement some of its recommendations. Efforts to publish and update handbooks should continue and expand in the future. Such handbooks should be evolving documents with frequent revisions to ensure their vitality.

### Conclusions

Some items in need of further research include

- Mobile/personal links in all the ITU allotted bands including the relevant choices of the propagation environment, ground antenna type and satellite orbit configuration as parameters.
- Rain climatology, including microstructure and seasonal effects.
- Rain attenuation models, including event duration distributions.
- Fade mitigation technology.
- Cloud effects for frequencies above about 30 GHz.
- Bands above about 17 GHz with emphasis given to low-margin applications.
- Low-latitude ionospheric scintillation effects (direct broadcast and aeronautical applications).
- Spectrum allocation for satellite applications via participation in regulatory processes.
- Computerized models for the prediction of propagation effects.
- Tools for the simulation of propagation effects.
- Maintenance and periodic revision of handbooks on slant path propagation.

The propagation community must stay abreast of the changing trends in the satellite communications market. This can be achieved by an ongoing dialogue with system planners and design engineers of satellite communication networks. The success of propagation research in the future will depend largely on how well the needs of the systems and engineering community are communicated to the propagation experts and experimenters.

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**NAPEX XVII**

**Session 1**

**SLANT PATH PROPAGATION STUDIES AND  
EXPERIMENTS**

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