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Frame Organization and Signalling for an Autonomous Switching Satellite

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System Aspects

To enhance the performance of communication satellite networks the use of on-board processing satellites with regenerative transponders and baseband-switching is under investigation since the mid-seventies. New satellite markets and traffic requirements together with the permanent increase of integration and speed of digital devices lead to a satellite, which acts as an autonomous switch in the sky.
The present paper describes the TDMA access scheme, the frame structures and a satellite-specific protocol developed for a german national study called 'Modular On-Board Switching System' (MOBS) [1], which makes network control and protocol processing on-board possible.

Access Technique with Demand Assignment

To cope with requirements as mixed services traffic, large number of small earth terminals, multi-beam coverage and constraints in frequency allocations, for the Uplink to the autonomous switching satellite, a 'Time Division Multiple Access' (TDMA) - System with Demand Assignment is considered. Since the content of a Downlink-Frame is generated exclusively by only a single source, namely the satellite, a pure Time Division Multiplex algorithm is used for the Downlink.

The ideal access scheme for the Uplink essentially is the result of a tradeoff between throughput efficiency and message delay. To optimize the system with respect to bandwidth-efficiency and flexibility, the assignment of traffic channels is achieved in a pure Reservation-TDMA (R-TDMA) technique, managed by the On Board Control System (OBC). This kind of channel allocation guarantees the best utilization of bandwidth without any collisions of channels, as they would occur under high amount of traffic by usage of contention techniques like Slotted-ALOHA or modified versions of it [2,3]. The price which has to be paid for, is an increase of the total message delay. This results from the time between the transmitting of a request message of a terminal and the reception of a confirmation message from the OBC at the same terminal.

In contrast to that reservation technique, the demand requests of the traffic terminals are treated in a Fixed-TDMA mode to avoid additional delays. For that purpose each terminal with an authorization for transmitting via the regarded link has its own section at the beginning of a frame, called Reservation Burst, which is permanently assigned to this terminal, even if the terminal has no calls to transmit. This leads to a permanent link between the terminal and the OBC of the satellite, which is also used for synchronization of the terminals and monitoring messages.

The major drawback of a multiple-access system is the overhead of the TDMA-frames coming from the individual preambles and guard times of the various terminal bursts. Nevertheless to achieve a sufficient high frame efficiency, the length of the frame must be increased in comparison with pure TDM-systems. The frame length itself is a compromise between the frame efficiency and the amount of on-board memory. Due to the 'frame wise' storing of the channels to be switched, the memory size is directly proportional to the product of frame length and data rate. In our case the frame length is chosen to 20 ms, as well for the Uplink as for the Downlink (see next section).
As a consequence of the on-board protocol processing (see chapter Signalling) and channel allocation - which avoids the 'double hop' necessary if the processing is done on ground - the call set-up time is minimised, with respect to the proposed reservation technique for the traffic channels. These advanced on-board processing features support very well the completely implemented demand assignment functions as variable origin, variable destination and variable window [4] and lead to a bandwidth assignment, which can be adopted dynamically to the traffic amount.

Frame Organization

The following sections describe the frame organization of both transmit links. Since there is only one kind of Uplink respectively Downlink Frame in the system, all information running between the traffic terminals and the satellite is included in these two frames; the information consists of acquisition, synchronisation, signalling and monitoring messages and the speech and data channels themselves.

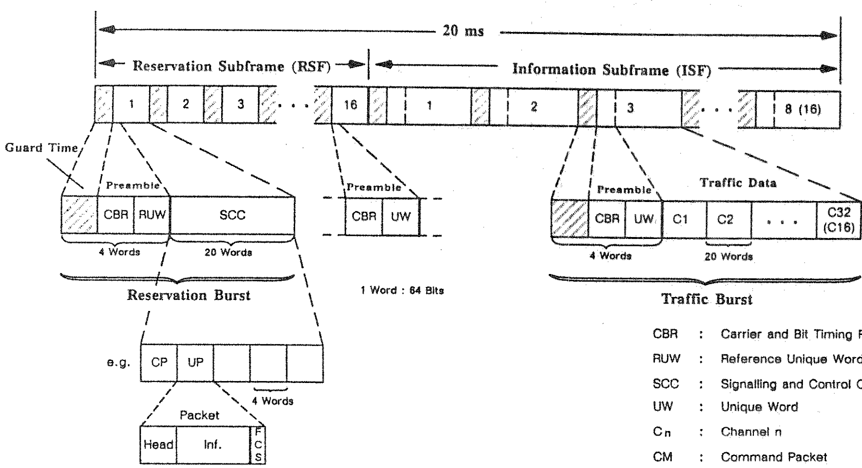
Uplink

The TDMA frame, which is shown in Figure 1, is divided into two parts: a Reservation Sub-Frame (RSF) and an Information Sub-Frame (ISF). In our case the TDMA-Frame should be accessed by a maximum of 16 traffic terminals with a net data rate of 16.384 Mbps (e.g. 256 channels with 64 kbps). Consequently the RSF consists of 16 Reservation Bursts, each containing a preamble followed by a field called Signalling/Control-Channel (SCC).

In accordance with terrestrial signalling channels each SCC has a capacity of 64 kbps and is able to carry up to five packets containing bandwidth requests, signalling, control and synchronization information (see chapter Signalling). Messages of the SCC, which have not to be processed on board, are sent transparently by means of a packet-switched technique via the OBC to the destined terminal. A burst preamble consists of a sequence for carrier and bit timing recovery (CBR) needed for the carrier demodulation. The CBR sequence is followed by a Unique Word (UW), which is a specific bit pattern used to reference the time of the occurrence of a burst. To indicate the beginning of a frame the first burst has a Reference UW (RUW), which differs from the other bit patterns. The guard time is necessary for the burst spacing because of the uncertainty in time of the accessing terminals. The RSF-Bursts are of constant length and position and will be transmitted by the terminals to achieve permanent synchronization, even if a terminal has no connection requests.

The ISF is made up of a maximum of 16 Traffic Bursts, each containing a preamble and 16 traffic channels, if e.g. a homogenous traffic distribution is assumed. The capacity of each burst can be changed dynamically on demand from 1 to 256 channels. In contrast to the packets of the reservation subframe the traffic channels of the information subframe are treated in a pure circuit-switched technique, also controlled by the OBC.

TDMA - FRAME



CBR : Carrier and Bit Timing Recovery
RUW : Reference Unique Word
SCC : Signalling and Control Channel
UW : Unique Word
C_n : Channel n
CM : Command Packet
UM : User Packet
FCS : Frame Check Sequence

Figure 1 : Frame Structure (Uplink)

On one hand the completely dynamical bandwidth allocation to the traffic terminals produces a great amount of signalling messages between the terminals and the satellite and therefore forces a considerable computing power of the OBC. On the other hand a frame management on the level of a single channel is not very effective because of the delay (~ 270 ms) of the satellite link. Therefore in the most cases it is recommendable, to perform the increasing and decreasing of bursts by bundles of channels (e.g. 2, 6,..) , depending on:

- the traffic characteristics of the system,
- the on board computing power and
- the available bandwidth for signalling.

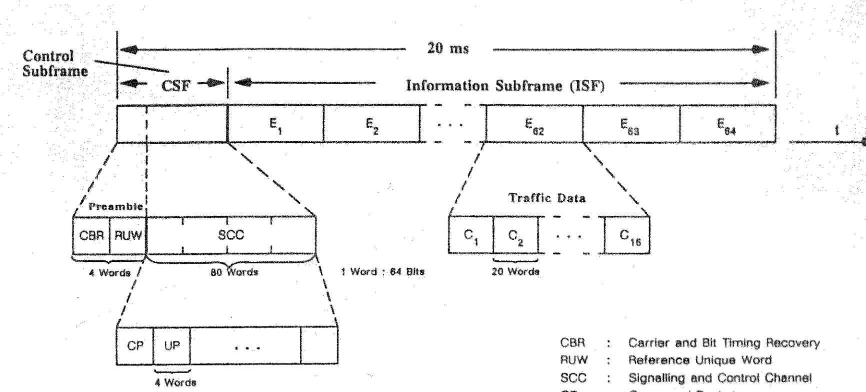
To obtain a sufficiently high frame efficiency for the uplink, the length of the TDMA frame was chosen to 20 ms (see section 'Frame Efficiency').

Downlink

Since only a single source exists for the Downlink, namely the satellite, the pure TDM technique for the access is used to achieve the best frame utilization. Therefore the TDM frame does not contain guard times and includes only one single preamble, which results in a very high frame eficiency.

The TDM-Frame shown in Figure 2 is divided into a Control Sub-Frame (CSF) and an Information Sub-Frame (ISF); also with a length of 20 ms, but with 4 times the capacity of an Uplink-Frame; therefore a Downlink frame consists of 1024 channels of 64 kbps , which results in a net rate of 65 MBps per frame. The asymmetrical architecture of the regarded system, which consists of 64 lower rate inputs and 16 higher rate outputs, results from the constraints of high frequency reuse in the uplink (multi spot system) and the limited number of output power amplifiers on board of the satellite.

TDM - FRAME



CBR : Carrier and Bit Timing Recovery
RUW : Reference Unique Word
SCC : Signalling and Control Channel
CP : Command Packet
UP : User Packet
E_n : Envelope n
C_n : Traffic Channel n

Figure 2: Frame Structure (Downlink)

Consequently the CSF is made up of a preamble and a SCC with 256 kbps. The SCC in the Downlink-Frame additional transmits the on-board generated Sync-Error-Messages to each terminal. The 1024 traffic channels of the ISF are logically structured in up to 64 envelopes corresponding to 64 traffic terminals.

Frame Efficiency

Since the availability of frequencies even in the 30/20 GHz band is permanently running shorter, the efficient utilization of bandwidth and therefore the frame efficiency is a very important point.

Generally the frame efficiency is calculated by the ratio of bits available for the traffic channels to the sum of all bits of the whole frame, including all overhead necessary for satellite transmission and switching. Figure 3 shows the frame efficiency for the Uplink and Downlink of the regarded system. Curve 1 stands for the access of 16 terminals to an Uplink frame, each consisting of a SCC with a capacity of 64 kbps. For the chosen frame length of 20 ms, the frame efficiency is calculated to 92 %, which is a good value for a TDMA frame. If the capacity of the SCCs of the terminals is reduced to 32 kbps, the frame efficiency increases by approximately 2 % (curve 2). Since the Downlink is driven in pure TDM, the efficiency is better than 99 % (curve 3). The influence to the efficiency of the number of accessing terminals to the Uplink frame is shown in Figure 4.

The results of the frame calculation offer, that even TDMA systems with permanently assigned SCCs consist of a very good performance, as far as the number of accessing terminals is limited, in our case approximately at two dozen. It should be noted, if the values of the frame efficiencies are compared with other TDMA systems, that the SCCs of the presented system likewise carry the 'end to end' signalling information. For that reason the actual frame efficiency still is higher as in the calculation made above.

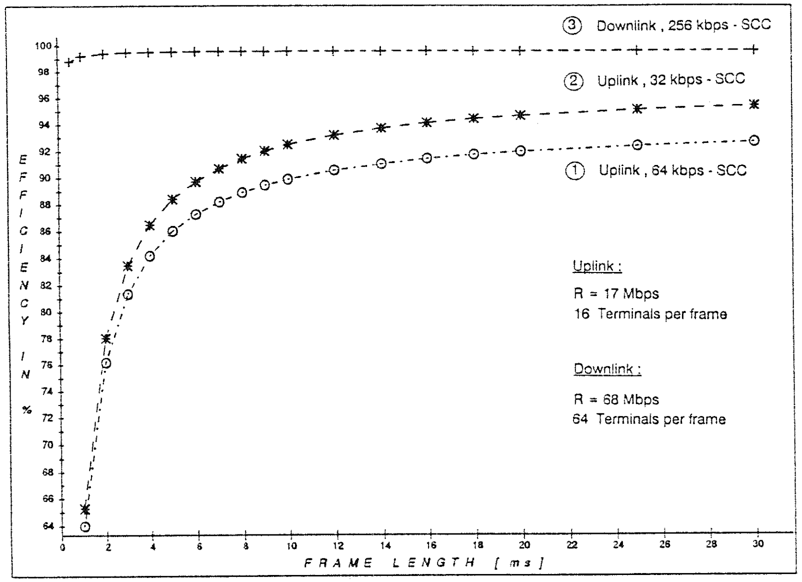


Figure 3: TDMA - / TDM Frame Efficiency

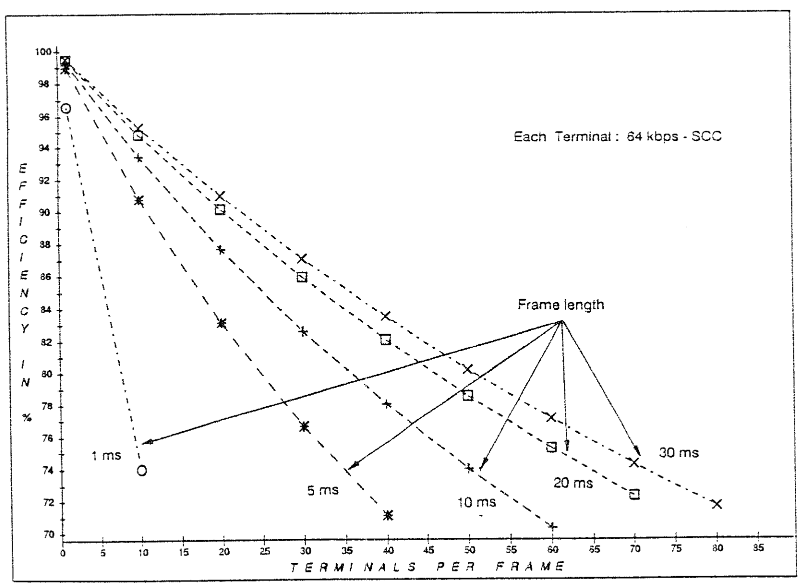


Figure 4: TDMA efficiency via accessing terminals

Signalling

Basic Aspects

Since MOBS is used as an intelligent switching node in the sky it is necessary to exchange information between the earth stations and the satellite. In addition to signalling messages used for establishing and clearing connections between terminals and the satellite, end-to-end signalling messages must be supported. Also services for operation and maintenance of the satellite system have to be provided. For all these communication needs a suitable signalling system must be implemented.

In the terrestrial Integrated Services Digital Network (ISDN) the signalling system CCITT No.7 [5] is used to transfer signalling information between exchanges. In principle the same signalling system could be used for the proposed satellite system making it easy to integrate it into an ISDN-based world. Since no end-users are directly connected to MOBS, it would behave like a transit exchange in an ISDN environment.

The use of CCITT No.7 within a satellite system raises some problems. Since CCITT No.7 is a very powerful signalling system not all services provided by it are necessary in a satellite system. Also the effort to implement CCITT No.7 is very high. Because of the restrictions that are caused by a satellite environment it is currently impossible to integrate CCITT No.7 into a satellite system with existing technology. It would therefore be necessary to move call control to a master earth station. Although this allows the use of CCITT No.7, there would still be need for a dedicated protocol between call control in the satellite. This realization doubles transmission delay of signalling messages and reduces the benefits of on board processing. Also the use of MOBS in non-ISDN environments would be restricted, because extensive interworking procedures must be implemented within the terminals. With these problems in mind, a decision was made to develop a sophisticated yet simple protocol specially designed to suit the needs of the satellite switching system.

Protocol Architecture

The protocol architecture developed for this environment is similar to the Basic Reference Model for Open Systems Interconnections (OSI) [6] (see Figure 5). Layer 1 provides the physical transport service. Layer 2 adds procedures for error free transmission of frames between terminals and the satellite. Layer 3 provides functional and procedural means for establishing and clearing physical connections.

Wherever possible elements from well known protocols were used. For Layer 2 the High Level Data Link Control (HDLC) procedure [7] is chosen. The throughput of the signalling system can be enhanced by adding a selective repeat approach. Instead of discarding and retransmitting all frames starting with the disrupted frame, only the erroneous frame is selectively rejected and retransmitted.
The layer 3 protocol was specially designed for the satellite and completely specified using the Specification and Description Language (SDL) [8]. This protocol introduces two different packet types, Control Messages (CM) and User Messages (UM). Control messages are used to communicate with the satellite, e.g. requesting channel assignments for incoming calls. User messages provide

the means to transfer end-to-end signalling information and any additional information that may need to be exchanged between earth terminals. The information of the user messages are not processed by the OBC but transferred transparently over the satellite links.

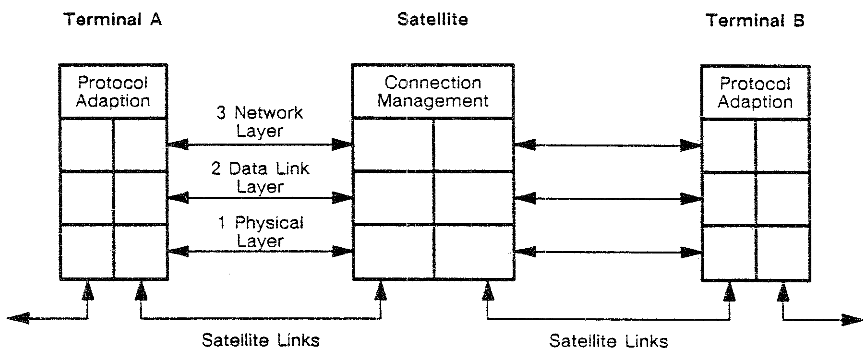


Fig. 5: Model of protocol Architecture

The use of these concepts will be clarified in the following example that shows a complete call establishment (see Fig. 6). The call setup between terminal A and terminal B is initiated by an incoming connection request. Terminal A analyzes this request in order to determine the destination terminal B and the requested bandwidth for the call. Then it sends a control message to the satellite including the addresses of both terminals A and B as well as the demanded bandwidth. Because the routing of the call has already been done by terminal A, the satellite must only assign idle channels in the uplinks and downlinks of the terminals. A list of assigned channels is appended to the confirmation and indication control messages which are sent from satellite to Terminals A and B respectively. At that time both links are connected via the switching network within the satellite.

In order to speed up the call establishing phase, terminal A is able to send UMs with additional call parameters for terminal B during the time the satellite processes the call request. These parameters are not necessary for establishing the connection on the satellite links, and hence are transmitted transparently. This information includes the subscriber number which is needed by terminal B to route the call to its final destination. In case the call cannot be established these UMs are discarded by the satellite. After terminal B has received the indication message and any additional parameters it continues the call setup. Note that all remaining signalling messages are transferred transparently as UMs.

The main advantages of this concept are:

- Simple protocol mechanism that can be easily implemented in the OBC and in the terminals.
- Simple interworking procedures for existing and future signalling protocols in the terminals.
  Therefore it is possible to connect several networks with different signalling procedures to one terminal simultaneously.
- Fast connection establishing.
- No master earth station necessary.

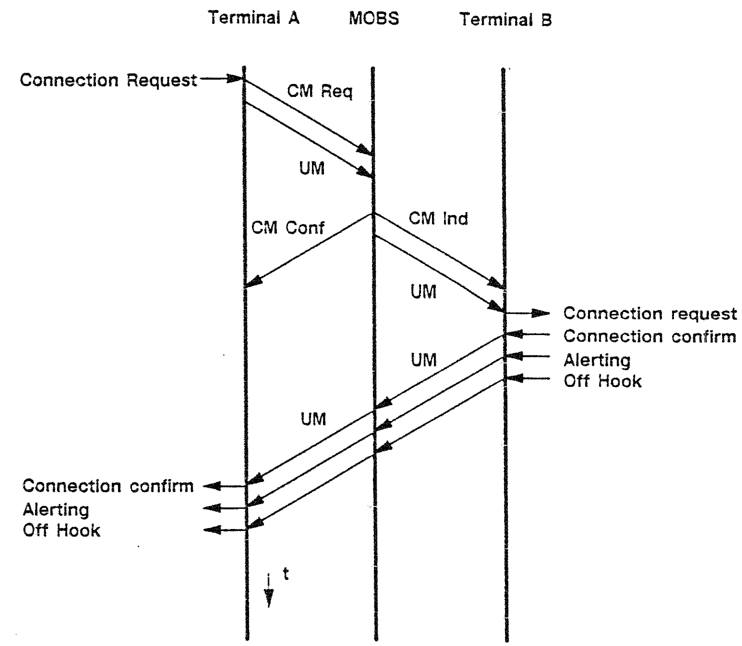
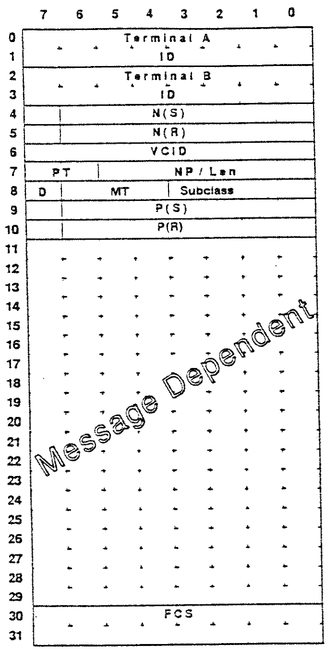


Fig. 6: Signalling Scenario for Call Setup

Implementation Aspects

All signalling messages are processed by the On-Board-Control (OBC) system. The OBC is a multiprocessor system with several Signalling- and Switching Controllers (SSC) [9]. A SSC handles all connections of several terminals. All frames belonging to connections initiated by terminal A are processed by the same SSC. Due to this implementation, the amount of internal communication is kept to a minimum. Frames are identified by terminal identifiers (ID). Both terminal IDs always stay in the same position within the frame, no matter if the frames are sent from terminal A to terminal B or vice versa (see Fig. 7). For the distinction of the direction a special bit, the so called direction bit was introduced.

In order to keep hardware and software implementation in the satellite as simple as possible, a fixed frame length of 32 Bytes was chosen. Frames are synchronously transmitted in the Reservation Subframe. Therefore no flags are necessary between frames. Also all frames appear on the internal high speed bus at specific times only. With some special hardware it is very easy to extract signalling messages from the bus and distribute them to the Signalling and Switching Controllers.



Terminal A/D Terminal A identifier
This field holds the address of the calling terminal.

Terminal B/D Terminal B identifier
This field holds the address of the called terminal.

D Direction
This bit decides if a frame is sent from A to B or vice versa.

N(S), N(R) Flow Control Layer 2

FCS Frame Check Sequence

PT Packet Type

NP/Len Number of Packets/Packet Length.
These fields control the correspondence of layer 2 frames and layer 3 packets. The following rules apply :

PT=0 Packet consisting of 1 frame NP/Len=Number of valid bytes within frame
PT=1 Start frame NP/Len=Number of frames
PT=2 Follow-up frame NP/Len=Number of frames that follow
PT=3 Last frame NP/Len=Number of valid bytes within frame

MT Message Type.
This field indicates the message type, e. g. Control Message, User Message, ...

Subclass This field allows the further subdivision of the message types.

P(S), P(R) Flow Control layer 3.

VCID Virtual Connection Identifier.
This field is necessary to differentiate between connections that belong to a specific terminal. Each connection in the satellite system can be identified by means of Terminal A/D and VCID together.

Bytes 11 trough 29 hold the actual packet information. Depending on the selected message type, these bytes may contain user data (e. g. User Messages) or commands and parameters (e. g. Control Messages).

Figure 7: Layer 2 and 3 message format

Each SSC is connected to its own Signalling Message Gate (SMG) which has a list of terminal A identifiers. If a signalling frame appears on the bus that has a terminal A ID which is in this list, the frame is copied to the input buffer of the corresponding SSC. By changing the list in the SMGs the number of assigned terminals can be adjusted for each SSC. With this concept load sharing dependent on terminal traffic can be easily done. If a SSC fails, its terminal can be assigned to the remaining SSCs which allows graceful degradation of the system. Special reserved IDs allow terminals to broadcast messages to all SSCs. This is a useful feature during system startup and error recovery.

Because the length of layer 3 packets is variable, several layer 2 frames may be logically chained to constitute one layer 3 packet. Information used for layers 2 and 3 is provided only once, which results in a very efficient frame structure. This can be done because all information is processed by the same SSC. A message type field not only differentiates between User Messages and Command Messages, but also allows the introduction of new message types, like Maintenance Messages. For a short description of the remaining fields see Figure 7.

Conclusion

The general utilization of on-board processing satellites certainly depends on the degree of their integration in the terrestrial networks. This paper suggests solutions for the frame organization and signalling problems of an intelligent switching satellite working in a TDMA environment, whereat even the signalling processing and switching control is performed on-board. It is outlined that the adaption to the different terrestrial protocols is done in the terminals on ground. For the signalling between the terminals and the satellite a new protocol is described, which supports terrestrial standards and suits satellite applications very well.

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