Synchronous TDMA Direct Satellite Broadcasting Network

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Abstract
A new direct satellite broadcasting network is proposed to solve the fundamental problem with existing DSB network. The problem is the lack of direct accessibility to the satellite for the transmit side. The conventional DSB networks are of a very centralized structure; the broadcasting station is limited to a single site and all channels signals are transmitted from the central station to the satellite. Direct broadcast from remote sites is impossible; a communication link must be established between the remote site and the central station, which is inconvenient and expensive. This centralized transmission side structure tends to bring about impoverishment of the broadcast contents and premature saturation of the market.
The system proposed herein can solve the problem. Multiple stations located anywhere within the satellite coverage area can directly transmit signals to the satellite transponder shared in a synchronous TDMA mode and the combined signal from the satellite can be received with existing DSB receivers. Normally up to 10 stations can share a transponder for standard TV broadcasting. The transmit stations can be VSAT with 1.2-2.4m antennae. Direct live reporting from the event sites with SNG vehicles will be also possible. Thus the proposed system provides a truly direct satellite broadcasting for the transmit side as well as the receive side. The wide area, single hop and direct access features of satellite communications can be fully utilized.
A historical review and technical principles and performances of Synchronous TDMA and its application to DSB networks are presented in this paper. The proposed system can realize a universal nationwide broadcasting network for the general public. It is expected that the system will integrate remote areas with national networks and open a new information age in the 21st century.

1. Status and Tasks of Direct Satellite Broadcasting (DSB) today

In Japan, the number of subscribers of SkyPerfecTV has saturated at 4 million, which is only 10% of the potential market. The direct cause is lack of good contents. More fundamental cause, in my opinion, is the monopoly of the service provider and limited location of the transmit stations. The service provides for the DSB through CS (communication satellites) have merged to a single company and all transmit stations exist in Tokyo area. In order to conduct live broadcasting from a remote area, it is necessary to establish a long distance access link from the remote site to the satellite feeder station in Tokyo, which is time-consuming and expensive. The long distance link can be provided by a satellite link, but the double hop satellite links also double the signal transmission cost. Considering those problems, it will be essential to develop a new system that enables direct broadcast transmission to the satellite from multiple sites anywhere and reception of the signals with conventional DSB user terminals existing everywhere within the coverage area of the satellite. This paper presents such a system based on Synchronous TDMA technology.

2. Synchronous TDMA and Its Application to DSB Network

2-1. TDM and TDMA

In digital DSB systems a number of different channels signals are multiplexed in Time Division Multiplex (TDM) mode to form Transport Stream (TS) for transmission to the satellite. All signals can be transmitted from a single station and can be received anywhere within the coverage area of the satellite. This central structure of the network does not enable direct transmission from multiple sites and strictly limits the application fields of the network to conventional, one way and power centric broadcasting. .

The Time Division Multiple Access (TDMA) allows direct, simultaneous and independent transmission from multiple sites to the same satellite transponder. The stations share the same transponder in TDMA mode. Each station transmits a burst of finite time length. In order to avoid collision of bursts from different stations, each station conducts Burst Timing Control. The TDMA can be classified into two types; asynchronous and synchronous. In the asynchronous system given are Guard Time (GT) of a few symbols before and after each burst and the burst timing control is made to contain the burst within the GT. Timing error can exceed a few symbols so long as the burst is contained within the GT. In the synchronous TDMA, all burst are fully synchronized to the phase of the symbol clock hence no guard time greater than half s symbol becomes unnecessary. In synchronous TDMA all signals are fully synchronized and look as if sent from the same station hence the signal can be received with conventional DSB receivers everywhere. Table 2-1 gives a list of satellite TDMA systems

Table 2-1 Parameters of various TDMA systems

System	Development Time and body	Frame length	Data rate	Clock Synch. mode	Notes
SMAX	1967-72 NTT Public Corporation	125 (μsec)	13.664(MHz)	Synch.	Verified feasibility of Synch TDMA by joint satellite experiment between Japan and USA
Sub-Mil-Wave TDMA	1974-82 NTT Public Corporation	328 (μsec)	64(Mbps) BPSK	Synch.	Commercialized as back-up for 8 RC stations, the highest hierarchy in telephony nwk.
Remote Islands TDMA	1974-82 NTT Public Corporation	105(μsec)	105(Mbps) QPSK	Synch.	Provided 192 telephony and 2 TV channels to Ogasawara Islands
Intelsat TDMA	1975-84 Intelsat	2 (ms)	120(Mbps) QPSK	Asynch.	International communication
Others	Various TDMA systems were developed in Japan, Europe, USA and Canada for varieties of objectives. All systems adopted Asynchronous methods for burst control.				
DSB TDMA	2003— Proposed	30 (ms) (TV frame)	42.192(Mbps) QPSK (DVB-S spec)	Synch.	This proposal

2-2. Application of Synchronous TDMA to DSB

<u>Basic functions;</u>

(1) Up to 10 earth stations (ES) share a satellite transponder (capacity; 30Mbps) in Synch.TDMA mode.

(2) A Reference earth Station (RES) transmits Reference Burst generated at its stable time base.

(3) All other Feeder Earth Stations (FES) synchronize their bursts with the RES burst by satellite loop PLL.

(4) The RES and FES bursts combine at the satellite to form a clock coherent downlink signal.

(5) The clock coherent and continuous downlink signals can be received with existing DSB receivers.

<u>Features</u>

(1) Direct transmission to the satellite from multiple sites can be applied to conventional DSB systems.

(2) The video and audio coding techniques for the satellite and terrestrial systems are common, hence complimentary development of DSB will be possible with the digitalization of broadcast networks.

3. Basic Specification of the Proposed System

3-1. Link Power Budget

Table 3-1 shows an example of power link budget for Japan. Similar parameters apply to many satellite systems in the world with similar sizes of coverage areas.

3-2. Earth Stations and User Terminals

The link power budget specifies the following sizes of the ES and UT (user terminal)

Feeder Earth Station (FES);- Antenna with 1.2m diameter
- High Power Amplifier with saturation power at 700W
- Transmitter Power Margin; 13,7 (dB)

User Terminal (UT) - Conventional DSB receiver (G/T= 10 dB/k)

3-3. TDMA Frame structure

The multiplex format in the proposed system follows DVB specification.

[1] Frame period - 30 (ms) ; Frame frequency of TV ; 29.97 Hz

[2] Data rates;

(1) Modulation ; 42.192Mbps

(2) Information (Mbps) ; 19.4 (1/2), 25.9 (2/3), 29.2 (3/4), 32.4 (5/6), 34.0 (7/8) (Punc. Ratio of conv. codes)

[3] Multiplex method

(1) A number N of TS packets (188 bytes) form a burst. N is allocated to the FES by the system.

(2) The Reed-Solomon coding is applied based on DVB-S specification to form 204-byte TS packets.

(3) Let the nominal convolutional coding puncture ratio 3/4, then

TS packet length = 204 x 4/3 = 272 (bytes) = 2176 (bits)

(4) The burst is composed of multiples of 8 packets; processing unit for FEC puncturing and randomization

(5) Example TDMA frame

Number of packets per frame ; 648 (1,410,048 bits)

Frame frequency ; 42.192 (MHz) / Number of bits = 29.92 (Hz)

[4] Burst format

(1) The first packet in a burst contains fixed patterns for carrier and clock recovery at the receivers.

(2) Subsequent packets can fully carry information data.

(3) The randomization PN code is initialized at the start of every 8 packets.

(4) Some of the final 12 packets can not carry information data because of interleave processing. But they can be used for inter-ES communication.

Table 3-1 Link Power Budget

<table>
<tr><th>Item</th><th colspan="2">Specification</th><th>Notes</th></tr>
<tr><td>Uplink</td><td colspan="2"></td><td></td></tr>
<tr><td>Feeder Earth Station</td><td colspan="2"></td><td></td></tr>
<tr><td>HPA output power (dBW)</td><td colspan="2">13</td><td>RF power 20W</td></tr>
<tr><td>Transmit Antenna Gain (dBi)</td><td colspan="2">43</td><td>Diameterr1.2m, Efficiency; 60%</td></tr>
<tr><td>Feeder loss (dB)</td><td colspan="2">0.5</td><td></td></tr>
<tr><td>EIRP (dBW)</td><td colspan="2">55.5</td><td></td></tr>
<tr><td>Free Space Loss (dB)</td><td colspan="2">207</td><td>RF; 14(GHz)</td></tr>
<tr><td>Satellite</td><td colspan="2"></td><td>JCSAT-4 class</td></tr>
<tr><td>G/T (dB/K)</td><td colspan="2">10</td><td>Geuss</td></tr>
<tr><td>Boltzman constant k (dB)</td><td colspan="2">-228.6</td><td></td></tr>
<tr><td>Uplink C/No (dB/Hz)</td><td colspan="2">87.1</td><td></td></tr>
<tr><td>Downlink</td><td colspan="2"></td><td></td></tr>
<tr><td>Satellite</td><td colspan="2"></td><td></td></tr>
<tr><td>Transponder Output (dBW)</td><td colspan="2">18</td><td>75W, 12GHz</td></tr>
<tr><td>Antenna gain (dBi)</td><td colspan="2">37</td><td>Efficiency 1/2</td></tr>
<tr><td>Feeder loss (dB)</td><td colspan="2">0.5</td><td></td></tr>
<tr><td>EIRP (dBW)</td><td colspan="2">54.5</td><td></td></tr>
<tr><td>Free Space loss (dB)</td><td colspan="2">206</td><td>12 GHz</td></tr>
<tr><td>Receiver</td><td>User Terminal</td><td>Earth station</td><td></td></tr>
<tr><td>G/T (dB/K)</td><td>10</td><td>17</td><td>Ant. Dm; 0.5 /1.2(m)</td></tr>
<tr><td>Bolzman constant k (dB)</td><td colspan="2">-228.6</td><td></td></tr>
<tr><td>Downlink C/No (dB/Hz)</td><td>87.1</td><td>94.1</td><td></td></tr>
<tr><td>Overall C/No (dB/Hz)</td><td>84.1</td><td>86.3</td><td></td></tr>
<tr><td>Data Rate (dB.Hz)</td><td colspan="2">75.0</td><td>30 Mbps</td></tr>
<tr><td>Eb/No (dB)</td><td>9.1</td><td>11.3</td><td></td></tr>
<tr><td>Operation Eb/No (dB)</td><td colspan="2">5.0</td><td></td></tr>
<tr><td>Link margin (dB)</td><td>4.1</td><td>6.3</td><td></td></tr>
</table>

4. Methods and Performances of Satellite Loop Clock Synchronization

4-1. TDMA Signal Multiplex on the Satellite

Multiple Feeder Earth Stations (FES) send data bursts signals to a common satellite transponder. The signals are combined on the satellite to form a single sequence for the downlink signal. The bursts timing is controlled to avoid collision with the bursts from other FES. One of the earth stations is designated as a reference earth station (RES). The RES transmits a reference burst which defines the TDMA frame. Then each FES transmits its data burst to the assigned time slots on the TDMA frame. The combined frame is depicted in the following figure.

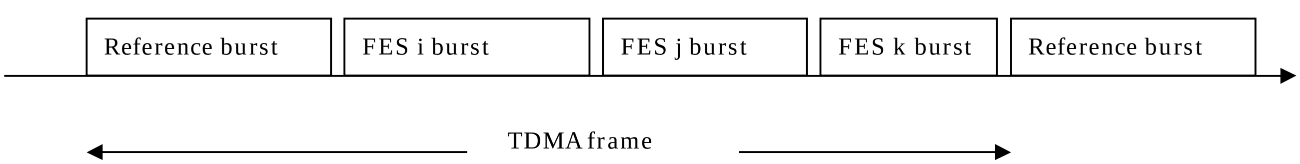

Figure 4-1 TDMA frame structure

4-2. Clock Synchronization System

Every FES must synchronize its transmit clock with the RES clock on the satellite. The downlink signal then becomes a clock coherent signal. The FES receives the downlink signal which contains all bursts from the FESs., The clock components are generated by square law detection of the receive signals. The FES then regenerates a continuous RES clock from the detected RES bursts clock components by a receive phase lock loop (Rx PLL). The recovered RES clock gives the clock reference at the FES. The FES compares the phase of its own square law detected burst clock with the clock reference. The detected phase error is then smoothed by Loop Filter and control the transmit clock generating voltage controlled oscillator (Tx VCO). The output of Tx VCO is used to generate the transmit burst signal to be sent to the satellite. The transmit phase lock loop (Tx PLL) contains the long satellite loop delay hence must be of a very narrow bandwidth for loop stability. The structure of the clock synchronization system is depicted in Figure 4-2.

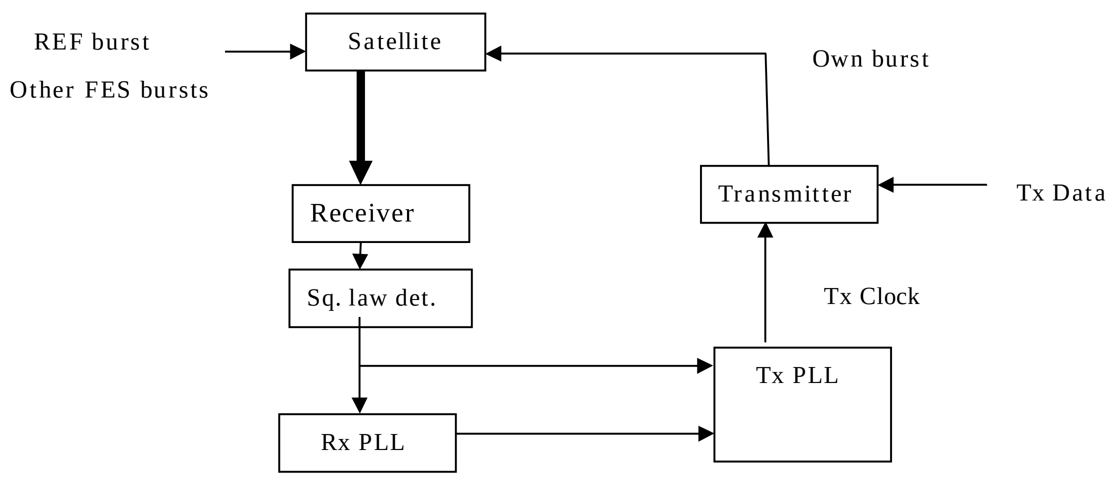

Figure 4-2 Structure of Clock Synchronization System

4-3 Rx PLL

The structure of the Reference Clock recovery Phase Lock Loop (Rx PLL) is depicted in Figure 4-3.

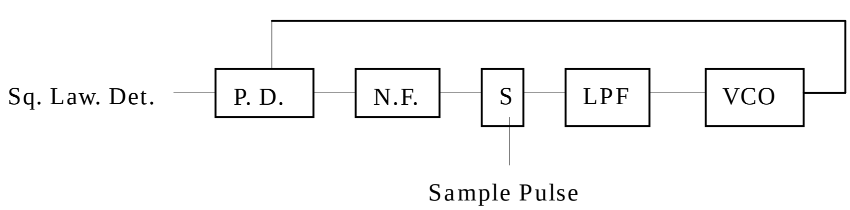

Figure 4-3 Structure of Reference Clock recovery PLL (Rx PLL)

The amplitude of a QPSK modulated signal changes with the modulating signal, hence a square law detector can regenerate the clock components. The Rx PLL compares the phase of Rx Clock VCO with the Square Law Detector output. The phase comparator output is smoothed by noise rejection low pass filter (Noise Filter) before a sampler. The sample timing shows the end of the reference burst (Ref burst). The sampled value is held until the next sampling. The sample & held value is smoothed by Loop Filter (LPF) to control the Rx Clock VCO.

The sampling frequency is the TDMA frame frequency which is 30 Hz. The bandwidth of the RX PLL is designed to be around 1/10 of the sampling frequency, or 3 Hz. A significant S/N degradation can occur at the Noise Filter and Sampler. The sampling causes the spectrum fold-over which increases the noise density by the ratio [Bandwidth of Noise Filter] / [Sampling frequency]. We specify the burst length be at least 1/10 of the frame then we have at most 10 dB degradation of the noise density. Another S/N degradation of about 10dB occurs at the square law detector. All the other processing are linear operations. The ratio of approximately 30 MHz of the receive signal over the Rx PLL equivalent noise bandwidth of 3 Hz gives 70 dB S/N improvement. Deduction of the above degradation gives about 50 (dB) S/N improvement by the Rx PLL. Even when the input S/N is 0 dB, the Rx PLL output S/N becomes 50 db; (the variance of) the phase error is only 0.13 degree.

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4-4. Tx PLL

The structure of Transmit Clock generating Phase Lock Loop (Tx PLL) is depicted in Figure 4-4. The structure of Tx PLL is the same as Rx PLL except that the sample pulse shows the end of its own burst and the PLL includes the long satellite loop delay.

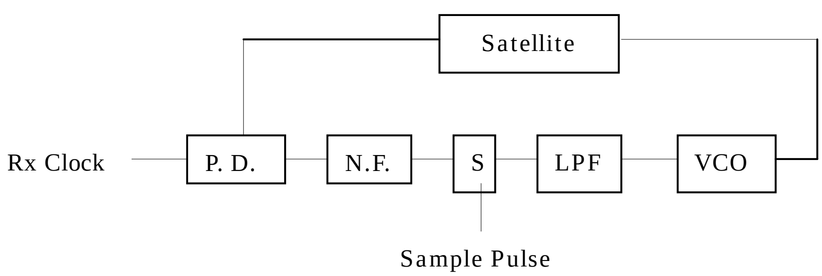

Figure 4-4 Structure of Transmit Clock PLL (Tx PLL)

The satellite loop delay is about 0.27 sec hence the bandwidth of Tx PLL must be designed to be narrow enough to guarantee the stability of the PLL.

Based on the previous works [1],[4], the following loop parameters are adopted;

Loop parameters;

Natural frequency	;	ωn = 0.924 (rad/sec)
Damping factor	;	ζ = 0.707
Equivalent noise bandwidth	;	BL= 0.49 (Hz)
Loop gain	;	Ko = 290 (/sec)
LPF time constant	;	To = 340 (sec)
Satellite Loop Delay	;	τ = 0.27 (sec)

Loop stability;

The Bode diagram analysis on the Tx PLL with the above parameters gives the following margins;

Phase Margin	; 43 (degrees) at $\omega/\omega n$ =1.4
Gain margin	; 12 (dB) at $\omega/\omega n$ =19.0

VCO Phase Noise

For such a narrow band PLL, the resultant phase error is dominantly caused by the phase noise within the VCO. The phase noise is characterized by phase noise power density spectrum $/\phi(j\omega)/^2$ which generally has the following components..

$$/\Phi(j\omega)/^2 = \alpha/2Ba + \beta/\omega^2 + \gamma/\omega^3$$

The first term is the additive noise component with bandwidth Ba and the total phase noise power α, the second term is the random walk noise and third is 1/f noise components.

Another frequently used characterization of the oscillator phase noise is the average phase drift over time τ, which is defined as follows. Let the phase of the oscillator $\phi(t)$, then the average time drift $\Delta\phi(\tau)$ is defined as $/\Delta\phi(\tau)/^2 = <\{\phi(t) - \phi(t-\tau)\}^2>$, where <x> means the time average of x.

It can be shown that the above two expressions are related as follows;

$$/\Delta\phi(\tau)/^2 = \alpha + \beta.\tau + \gamma.\ \tau^2$$

The frequency stability function $S(\tau)$ of an oscillator with frequency fo is defined by

$$S(\tau) = \Delta\phi(\tau) / (2\pi fo.\ \tau)$$

For large τ, the phase drift is dominantly caused by 1/f noise and the frequency stability of the oscillator tends to be constant;

$$S(\tau) = \sqrt{(\gamma)} / (2\pi fo)$$

Tx PLL phase error

It can be shown the resultant phase error in PLL with damping factor $\zeta = 1/\sqrt{(2)}$ is given by the following formula;

$$/\phi e/^2 = \alpha + 3\beta/16/BL + 9\gamma/128/BL^2$$

The phase noise performance of crystal oscillators today is quite good. For example, a commercial VCXO (ex. 7100 series , NDK) gives the following performance

$$/\Phi(j\omega)/^2 \quad = -50\ (dBc/Hz)\ at\ 1(Hz)$$
$$= -80\ (dBc/Hz)\ at\ 10(Hz)$$

which gives

$$\gamma = 2.5 \times 10^{-3}$$
$$\beta < 4.0 \times 10^{-5}$$

Then the resultant phase error of Tx PLL with BL = 0.49 (Hz) is

$$/\phi e/ = 0.027\ (rad) = 1.57\ (deg)$$

Thus a very accurate synchronous TDMA is technically feasible.

5. Comparison with SkyPlex system

In Europe a system called SkyPlex is in operation. The objective of this proposed system is the same as that of SkyPlex In Europe there are many countries with different languages within the coverage areas of the communication satellites. With development of EU people move to different countries more freely. There arise naturally demands for a DSB system that enables direct transmission to the satellite from many different countries and the combined signal can be received by conventional DSB receivers all over Europe. In SkyPlex the uplink signal is in single channel per carrier (SCPC) in frequency division multiplex (FDM) mode. The uplink signals are demodulated and the data sequences are regenerated on the satellites. The regenerated signals are re-multiplexed into time division multiplex (TDM) format as specified in the DSB system. The SkyPlex system allows a very small FES because a single channel is sent in a continuous mode and achieves a perfect compatibility with conventional DSB system. However, the SkyPlex system requires a special and fairly complex satellite. On the other hand the proposed Synchronous TDMA system is applicable to simple, bent-type satellites which are available all over the world.

6. Social benefits of the Synchronous TDMA DSB network

The proposed system is effective to provide a universal broadcasting and communication network for the wide areas covered by the satellites. Local industries can promote their products to the wide area markets through the DSB network. It will be effective to vitalize the local industry and develop national economy. It will also bring the nationwide broadcasting network much closer to the general public. A new industry will arise that will provide public access with the nationwide broadcasting network for local industries, governments, various groups and even individuals. The broadcasters may evolve to BSP corresponding to ISP in the Internet. Integration of the proposed network with the Internet realizes the Internet with full broadcast capability or an interactive nationwide broadcast network accessible even from the users' homes.

The FES can function as a Gateway Station for the local communication or broadcasting network. The Gateway can be Toll Switch in local telephony network, where the communication satellites provide the long distance trunk links in the sky. The nationwide broadcasting and communication can be integrated quite naturally. For example, 700 telephony and 2 TV channels can be carried through a transponder with a 30 Mbps capacity. The system will be effective for such areas where there are many remote islands or deep mountain areas. The system concept is depicted in the following figure.

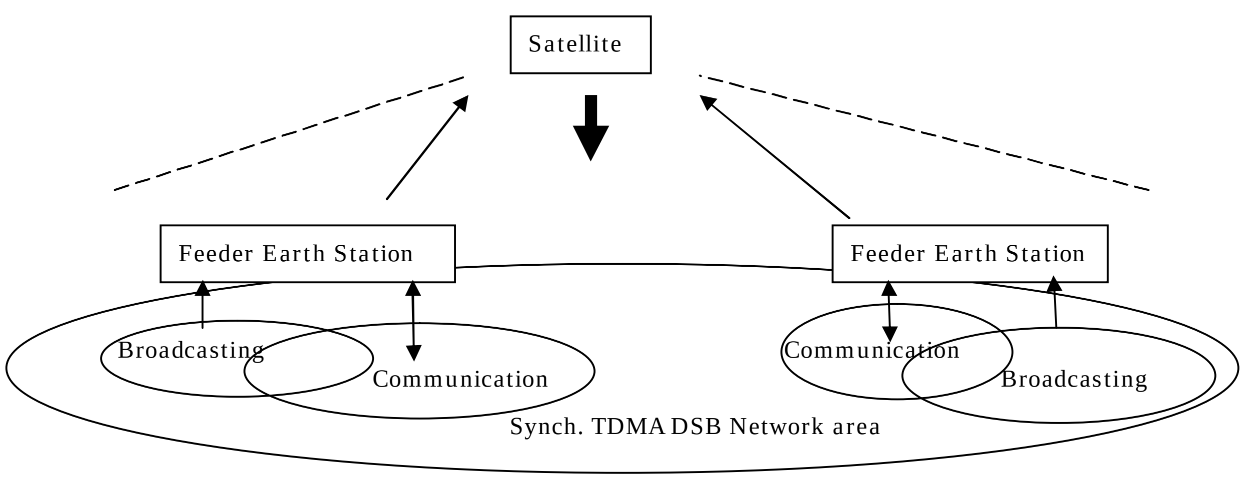

Figure 6 Integrated Communication and Broadcasting Network

Conclusion

The proposed system can realize a truly direct satellite broadcasting network for the transmitter sides as well as the receiver sides. The Synchronous TDMA is a field proven technology put into practice in Japan about twenty years ago. The wide area, single hop, direct accessibility features of the satellite communication networks can be fully utilized. The DSB network can evolve from conventional, centralized and one way STAR structure onto new, distributed and interactive MESH structure. The geographical universality and easy installation of the system is effective to integrate remote and local networks into the wide area broadcasting and communication networks. The universality of the system will be effective to vitalize local industries and national economy and will be useful for developing and developed countries as well.

References

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