16 Communications Payloads

16.4 Sample Missions

16.4.1 SCS

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For the Supplemental Communications System (SCS) design from Chap. 14, the target mass is 200 kg for each spacecraft, with all three spacecraft launched on a single rocket 21,000 km altitude. The primary design objective is the maximization of communications bandwidth, and the initial communications payload driving requirements are captured in Table 16web-1.

Table 16web-1. SCS Communications Payload Driving Requirements.

Mass	Maximum of 47 kg (plus 30% margin or 14.1 kg)
Power Consumption	214 W
Cost	Low-cost
Schedule	Not a major driver
Lifetime	5 years required, 7-year goal
Reliability	Assume this is not a driver, since it provides supplemental support
Delta V	90 m/s
Orbit	21,000 km, circular, 0 deg inclined, 12.5 hr period
Payload Accommodation • **Data Rate, Volume, and Latency** • **Pointing Requirements** • **Mass, Volume, Fields of View** • **Other**	Maximize data rate through payload, which translates to maximizing EIRP (forward link) and G/T (return link). Pointing of 1 deg accuracy to support intersatellite links. See text for more info
User Terminals	Small handheld, vehicular, semi-fixed
Gateway Terminals	Fixed as well as transportable gateways
Modulation and Coding	GMR-1 3G waveform, 31.25 and 62.5 kHz carriers

The target design point is 47 kg and 214 W for the SCS payload on each spacecraft. This establishes a starting point to consider reasonable payload configurations and assess against the communications mission objectives:

- Global communications to meet military needs
- Secondary mission, equal importance, natural disaster relief
- Communications content ranges from brief text, voice, to photos

The major spacecraft communications payload driver is the ability to accommodate small user terminals such as handheld and vehicular. For the return link (user to satellite), the satellite *G/T* must be large enough to close the link from a single user. For the forward direction (satellite to user), the satellite *EIRP* must be large enough to close the links to many users.

Gateway terminals are assumed to be large fixed terminals as well as smaller transportable terminals. Gateways terminals must track, with two antennas at each location, the two satellites simultaneously in view, and handoff from one to the other.

16.4.1.1 Satellite Communications Payload Drivers

Mass considerations immediately identify a very modest payload. This mass is further allocated into the communication payload and is apportioned to the return and forward payload and the two cross link payloads. The return payload includes the user receive antenna and the gateway transmit antenna. The forward payload includes the gateway receive antenna and the user transmit antenna. If included, a cross link payload for each satellite would include two transmit / receive antennas, to link to each of the other two SCS satellites.

Antenna considerations

Spacecraft antenna size is a key parameter in being able to close an uplink from a small user terminal such as a handset or vehicular mounted terminal. The limited payload physical size for a launch of three SCS satellite on the same launch vehicle indicates a maximum satellite antenna size of 1.6 m. One antenna is used for the L-band transmit (forward) and receive (return) user links. Another antenna is used for the C-band links to the gateway.

The spacecraft **user antenna** size and frequency determines the size of the coverage area on the ground. Full Earth coverage from the 21,000 km altitude requires a 26.8 deg antenna beamwidth, which would be a 50 cm antenna at L-band. Alternately, a 1.6 m L-band antenna would have 9 deg beams, either with seven 9 deg beams used for simultaneous Earth coverage or one beam electronically steered over the Earth to the communications mission area to provide links between the satellite and users.

The spacecraft **gateway antenna** is a second spacecraft antenna and is used for the links between satellite and gateway at C-band. The spacecraft is moving over the surface of the Earth, and the spacecraft must be able to keep both user antenna and gateway antenna correctly pointed. The same antenna is used for transmit (return) and receive (forward) gateway links.

Link performance is related to antenna size. For a fixed antenna size and clear weather operation, the link performance is the same over different frequency bands since the increase in antenna gain with increased frequency is exactly offset by the increased path loss with increased frequency.

For a fixed coverage area such as the 28 deg Earth as viewed from 21,000 km altitude, a single beam antenna has a fixed gain of 15.5 dBi for an assumed antenna efficiency of 55%. Size of this antenna changes with frequency:

- L-band: 50 cm
- S-band: 37 cm
- C-band: 18 cm
- X-band: 12 cm

Path loss and atmospheric loss are less at lower frequencies, so L-band and S-band are favored for links with small user terminals. For satellite to gateway links, a higher frequency such as C-band allows use of a smaller satellite antenna. The links between satellite and gateway are greatly facilitated by the potential large size of the Earth-based gateway, for example 7 m or more. Thus the antenna on the satellite for the gateway link can be smaller than the antenna on the satellite for the users.

For **intersatellite link (ISL) antennas**, higher frequencies are used such that atmospheric attenuation provides interference isolation between space and Earth. ISL frequencies and antenna sizes for a 1 deg beamwidth are:

- 23 GHz: 91 cm
- 32 GHz: 65 cm
- 60 GHz: 35 cm

The SCS payload does not include the two ISL antennas (for links to the other two SCS satellites) due the mass and power penalty which would greatly reduce user communication capacity.

Summary—for the SCS mission, the antenna trades lead to the following choices for the antennas on the satellite:

- Satellite to User: 50 cm fixed or 160 cm spot at L-band
- Satellite to Gateway: 15 cm Earth coverage at C-band (adequate for user links)
- Intersatellite links: None (payload cannot support without compromising user link capacity due to limited power)
- Each antenna carries forward and return traffic

Power—Spacecraft HPA power for the user forward link is chosen to be as high as possible, 100 W. For the return link to the gateway, 20 W power is adequate for the projected communications capacity.

Capacity—maximization of the payload communications capacity is the primary goal. Capacity can be increased a number of ways:

- Increase bandwidth (constrained by ITU regulations)
- Increase power (constrained by SCS payload limits)
- Decrease link distance (fixed, given SCS 21,000 km altitude orbit)
- Lower frequency (reduces path loss)
- Larger antenna. Baseline is Earth coverage antenna. Larger antenna gives smaller spot with consequent need for multiple spots or steering of spot

As the link assessment will show, the achievable capacity for the SCS design varies with the type of user terminals and whether the satellite has a fixed Earth coverage beam or a smaller spot beam. The use of the large 1.6 m user antenna on the SCS spacecraft gives better return capacity and enables communication with handheld terminals. The forward capacity is limited by the satellite L-band power and antenna size. The use of fixed antennas at L-band (0.50 m for Earth coverage) requires use of larger semi-fixed and fixed user terminals to close the return link.

16.4.1.2 Return Link Budget (Earth coverage antennas on satellite)

Table 16web-2 shows the return link budget using Earth coverage antennas on the satellite for user-to-satellite and satellite-to-gateway links. This allows use of small antennas, 50 cm at L-band for the user links and 15 cm at C-band for the gateway link.

The user terminal size and power is the factor that limits the return link data rate. Link budgets are given for three terminal cases (in three columns):

- Hand held terminal with single 2.5 kb/s voice connection
- Semi-fixed data terminal with multiple 2.5 kb/s voice connections
- Fixed user terminal with 64 kb/s data rate

The satellite has a fixed user antenna beamwidth of 27 deg. A separate gateway antenna on the satellite also has a 27 deg beamwidth at the 6.9 GHz downlink frequency, and the satellite return power is 20 W. This return power is shared among all users and all user types, and places the limit on total return capacity.

The design procedure is to make the satellite-to-gateway link as strong as possible to minimize its impact on end-to-end link performance. Even though the satellite antenna size and power are constrained, the gateway receive antenna on the other end of the link can be amply sized. The C-band 7 m gateway antenna size is 7 m and power is 200 W.

Live Calc

Table 16web-2.Return Link Budget: Use of Earth Coverage Satellite Antenna Requires Fixed Terminals for Users to Close Link.

SCS Return Link Cases	Units	Handheld	Semi-fix user	Fixed user	Comments and references	
User Uplink frequency	GHz	1.62	1.62	1.62	L-band uplink	Given
User terminal type		Handheld	Semi-fixed	Fixed		
Diameter	m	0.08	**0.5**	**2.0**		Input
Beamwidth	deg	162.0	25.9	6.5		
Gain	dBi	0.1	16.0	28.0	Assume 55% efficiency	
Power	W	1	**1**	**10**		Input
Backoff and line loss	dB	0.0	-3.5	-3.5	2 dB BO, 1.5 dB line loss	Assumed
User EIRP	dBW	0.1	12.5	34.5		
Propagation range	km	26,000	26,000	26,000		Given
Space loss	dB	-184.9	-184.9	-184.9		
Atmospheric losses	dB	-0.4	-0.4	-0.4		
Fade margin	dB	-3.0	0.0	0.0	Clear view of sky for fixed	Given
Net path loss	dB	-188.3	-185.3	-185.3		
Satellite antenna, type		Earth cover	Earth cover	Earth cover		
Diameter	m	0.50	0.50	0.50		Input
Beamwidth	deg	26.8	26.8	26.8		
Gain	dBi	15.6	15.6	15.6	Assume 50% efficiency	
Line loss on satellite	dB	-1.5	-1.5	-1.5		Assumed
Received carrier power, C	dBW	-174.2	-158.8	-136.7		
Sys.noise temp	dB-K	27.3	27.3	27.3		Assumed
Effective G/T, satellite	dB/K	-13.2	-13.2	-13.2		
Receiver C/No	dB-Hz	27.1	42.5	64.6		
User Data rate	dB-Hz	34.0	34.0	48.1		
Available Eb/No, uplink	dB	**-6.9**	8.6	16.5		
SAT-GW Downlink freq.	GHz	6.90	6.90	6.90	C-band downlink	Given
Satellite antenna type		Earth cover	Earth cover	Earth cover		
Diameter	m	0.15	0.15	0.15		Input
Antenna beamwidth	deg	26.8	26.8	26.8	26.8 deg Earth	
Antenna gain	dBi	15.6	15.6	15.6	Assume 50% efficiency	
Satellite transmit power	W	20	20	20		Input
Backoff and line loss	dB	-5.0	-5.0	-5.0	3 dB BO, 2 dB line loss	Assumed
EIRP, satellite	dBW	23.6	23.6	23.6		
EIRP per carrier	dBW	33.6	-1.4	4.1		
Propagation range	km	26,000	26,000	26,000		Given
Space Loss	dB	-197.5	-197.5	-197.5		
Atmospheric losses	dB	-1.5	-1.5	-1.5		
Net path loss	dB	-199.0	-199.0	-199.0		
Gateway terminal type		Tracking	Tracking	Tracking		
Diameter	m	7.0	7.0	7.0		Input
Beamwidth	deg	0.4	0.4	0.4		
Gain	dBi	51.5	51.5	51.5	Assume 55% efficiency	
Line loss	dB	-2.0	-2.0	-2.0		Assumed
Receive carrier power, C	dBW	-115.9	-151.0	-145.5	Single carrier	
System noise temperature	dB-K	26.0	26.0	26.0		Assumed
G/T, gateway	dB/K	25.5	25.5	25.5		
Receiver C/No	dB-Hz	86.7	51.6	57.1		
User Data rate	dB-Hz	34.0	34.0	48.1		
Available Eb/No, downlink	dB	52.7	17.6	9.1		
End-to-end Eb/No	dB	-6.9	8.0	8.3	Uplink plus downlink	
Required Eb/No	dB	-0.5	-0.5	5.3	GMR-1 3G waveform	
Link Margin	dB	**-6.4**	**8.5**	**3.0**	3 dB goal	Given
Carrier bandwidth	kHz	31.25	31.25	62.50		Given
User data rate	kb/s	2.5	2.5	64		Input
Users per carrier		4	4	1		Given
No. simultaneous carriers		0	320	90		Input
No. simulataneous users		0	1,280	90		
Total bandwidth	MHz	0.00	**10.00**	5.63	Limited to 10 MHz for SCS	Output
Total capacity	Mb/s	**0.00**	**3.20**	**5.76**	Maximize	Output
Link closes?		**No**	**Yes**	**Yes**		

GMR-1 G3 waveforms are used for the links, and determine user data rates, carrier bandwidths, and required Eb/No to close the links. Different waveforms are used for the three terminal types. The SCS system is able to support a mix of terminal types, within the capacity limits of satellite.

The entries in the return link budget are now discussed, starting with the uplink from the user. Frequency, user to satellite, is given in GHz. For this example, we are using an L-band user uplink frequency which will be subject to ITU coordination to avoid interference with other satellites at GEO and LEO.

Return Uplink (user to satellite)

User Uplink Frequency is 1.62 GHz (L-band)

User Terminal Types and Parameters are Input

Propagation Losses Include:

- Space loss is for the 26,000 km maximum range (21,000 km satellite altitude)
- Propagation loss is an assessment of the atmospheric losses, scintillation, and polarization losses. Atmospheric (rain) losses are low at L-band
- Fade margin is an assessment of line of sight blockage such as city buildings, trees, and wet foliage. It is assumed that semi-fixed and fixed user terminals will be located with a free line of sight to the satellite. The handheld user has a minimal 3 dB fade margin

Satellite Receive Antenna (signals from users)

- An Earth coverage antenna is assumed which has a 50-cm diameter at L-band
- Antenna efficiency is assumed to be 50%
- Antenna gain is computed to be 15.6 dBi
- Line loss is assumed to be 1.5 dB
- System noise temperature for the satellite is assumed
- Received carrier level C at receiver input is computed. Effective *G/T* is computed
- C/N_o is computed, where N_o equals Boltzmann's constant plus system temperature
- Data Rate is the single user data rate expressed in dB-Hz
- Available uplink E_b/N_o is calculated. Note that the handheld user terminal has too low a value to allow the uplink to close. No matter how high the downlink E_b/N_o, the end-to-end link can not close

Return Downlink (satellite to gateway)

The Downlink Frequency is 6.9 GHz (C-band)

Satellite Transmit Antenna

- Earth coverage antenna is assumed which has a 15-cm diameter at C-band
- Antenna efficiency is assumed to be 50%
- Antenna gain is computed to be 15.6 dBi
- Satellite transmit power is 20 W, backoff is 3 dB, and line loss is 2 dB (assumptions)
- Satellite *EIRP* is calculated based on satellite antenna gain and transmit power
- EIRP per carrier is the total satellite EIRP divided by the number of carriers

Propagation Parameters are as described for the return uplink, except the gateway link frequency is at C-band. There is no allocation for rain fade since the gateway is located with a clear view of the sky:

Gateway Terminal size is 7 m (input), and line loss is 2 dB (assumption):

- System noise temperature is 26 dB/K (assumption), based on a high gain antenna with low antenna temperature and a low noise figure receiver
- Received carrier level *C* at the gateway receiver input is computed
- Effective *G/T* for the gateway is computed
- C/N_0 is computed., where N_0 equals Boltzmann's constant plus system temperature
- Data Rate is the single user data rate expressed in dB-Hz
- Available downlink E_b/N_o is calculated. End-to-end E_b/N_o combines the uplink and downlink Eb/No. The required E_b/N_o to close the link is obtained from GMR-1 G3 waveforms numbers. 3 dB margin is desired at this stage of design. Note that the handheld link does not close

At the bottom of the link budget, the carrier bandwidth is given along with the single user data rate and number of users per carrier. The total capacity is computed.

The total bandwidth for SCS is limited to 10 MHz due to the limited spectrum likely to be available at L-band. This may limit link capacity which can be seen if the margin at the bottom of the link is greater than 3 dB.

The number of simultaneous users is adjusted (if possible) to have 3 dB margin. Number of users affects the downlink only, where the users share the satellite power.

The handheld user terminal end-to-end link does not close since the uplink does not close for the handheld user with Earth coverage satellite antenna. The semi-fixed terminal user return link easily closes and has margin greater than 3 dB since the end-to-end link total capacity is limited to 3.2 MB/s by the 10 MHz available bandwidth. The fixed user with 64 kb/s links has 5.76 Mb/s capacity.

Table 16web-3. Forward Link Budget: Use of Earth Coverage Satellite Antenns Requires Fixed Terminals for Users to Close Link

SCS Forward Link Cases	Units	Handheld	Semi-fix user	Fixed user	Comments and references	
Uplink frequency	GHz	5.100	5.100	5.100	C-band uplink	Given
Gateway terminal type		Tracking	Tracking	Tracking	2 GW ant. for 2 sats.	
Diameter	m	7.0	7.0	7.0		Input
Beamwidth	deg	0.6	0.6	0.6		
Gain	dBi	48.9	48.9	48.9	Assume 55% efficiency	
Transmit power	W	200	200	200		Input
Backoff and line loss	dB	-5.0	-5.0	-5.0	3 dB BO, 2 dB line loss	Assumed
EIRP, gateway	dBW	66.9	66.9	66.9		
EIRP per carrier		60.8	44.6	52.7		
Propagation range	km	26,000	26,000	26,000		Given
Space loss	dB	-194.9	-194.9	-194.9		
Atmospheric losses	dB	-5.0	-5.0	-5.0	Atmosphere	
Net path loss	dB	-199.9	-199.9	-199.9		
Satellite antenna, type		Earth cover	Earth cover	Earth cover		
Diameter	m	0.15	0.15	0.15		Input
Beamwidth	deg	26.8	26.8	26.8		
Gain	dBi	15.6	15.6	15.6	Assume 50% efficiency	
Line loss on satellite	dB	-1.5	-1.5	-1.5		Assumed
Received carrier power, C	dBW	-125.0	-141.2	-133.1		
System noise temp	dB-K	27.3	27.3	27.3		Assumed
G/T, satellite	dB/K	-13.2	-13.2	-13.2		
Receiver C/No	dB-Hz	76.3	60.1	68.2		
User Data rate	dB-Hz	34.0	34.0	48.1		
Available Eb/No, uplink	dB	42.4	26.1	20.2		
Downlink frequency	GHz	1.52	1.52	1.52	L-band downlink	Given
Satellite antenna, type		Earth cover	Earth cover	Earth cover		
Diameter	m	0.50	0.50	0.50		Input
Antenna beamwidth	deg	26.8	26.8	26.8	26.8 deg Earth	
Antenna gain	dBi	15.6	15.6	15.6	Assume 50% efficiency	
Satellite TX power	W	100	100	100		Input
Backoff and line loss	dB	-4.5	-4.5	-4.5	3 dB BO 1.5 dB line loss	Assumed
EIRP, satellite	dBW	31.1	31.1	31.1		
EIRP per carrier	dBW	25.1	8.8	17.0		
Propagation range	km	26,000	26,000	26,000		Given
Space Loss	dB	-184.4	-184.4	-184.4		
Atmospheric losses	dB	-0.4	-0.4	-0.4		
Fade margin	dB	-3.0	0.0	0.0	Clear view by fixed users	Given
Net path loss	dB	-187.8	-184.8	-184.8		
User terminal type		Handheld	Semi-fixed	Fixed	Fixed are steerable	
Diameter	m	**0.09**	**0.5**	**2.0**		Input
Beamwidth	deg	162.5	27.6	6.9		
Gain	dBi	0.0	15.4	27.5	Assume 55% efficiency	
Line loss	dB	0.0	-2.0	-2.0		Assumed
Receive carrier power	dBW	-162.7	-162.6	-142.4	Single carrier	
System noise temperature	dB-K	29.5	29.5	29.5		Assumed
G/T, user terminal	dB/K	-29.5	-14.1	-2.0		
Receiver C/No	dB-Hz	36.4	36.5	56.7		
User Data rate	dB-Hz	34.0	34.0	48.1		
Available Eb/No, downlink	dB	2.4	2.5	8.7		
End-to-end Eb/No	dB	2.4	2.5	8.4	Uplink plus downlink	
Required Eb/No	dB	-0.5	-0.5	5.3	GMR-1 3G waveform	
Link Margin	dB	**2.9**	**3.0**	**3.1**	3 dB goal	Given
Carrier bandwidth	kHz	31.25	31.25	62.50		Given
User data rate	kb/s	2.5	2.5	64		Input
Users per carrier		4	4	1		Given
No. simultaneous carriers		4	170	26		Input
No. simulataneous users		16	680	26		
Total bandwidth	MHz	0.13	5.31	1.63	Limited to 10 MHz for SCS	Output
Total capacity	Mb/s	**0.04**	**1.70**	**1.66**	Maximize	Output
Link closes?		**Yes**	**Yes**	**Yes**		

16.4.1.3 *Forward Link Budget (Earth coverage antennas on satellite)*

Table 16web-3 shows the forward link budget. Similarly to the return budget, Earth coverage antennas on the satellite are used for user-to-satellite and satellite-to-gateway links.

The satellite has an Earth coverage antenna for downlinks to users, and 100 W power at L-band. The power is shared among all users and all user types, and places the limit on total forward capacity (number of users and data rates).

The link budget for the satellite-to-user link has multiple carriers at the indicated data rate and terminal type (same as the return budget cases).

Similar to the return links, there are three user terminal types are used:

1. Hand held terminal with single 2.5 kb/s voice connection
2. Semi-fixed data terminal with 0.5 m diameter and 2.5 kb/s voice
3. Fixed user terminal with 0.5 m diameter and 64 kb/s data rate

The entries in the forward link budget with Earth coverage antennas on the satellite are now discussed, uplink first.

Forward Uplink (gateway to satellite)

The Uplink Frequency is 5.1 GHz (C-band).

Gateway Terminal has 7 m diameter and 200 W transmit power.

- Total gateway *EIRP* is calculated based on antenna gain and power
- Number of simultaneous carriers is adjusted so that the forward links close
- Total number of users is number of carriers times users per carrier
- *EIRP* per carrier is the total satellite *EIRP* divided by the number of carriers

Propagation Parameters are as described for the return downlink.

- Satellite antenna diameter is 15 cm with Earth coverage at C-band
- The noise calculation is as previously explained for the return downlink
- Receiver C/N_o and available E_b/N_o are calculated

Forward Downlink (satellite to users)

The Downlink Frequency is 1.52 GHz (L-band).

Satellite Transmit Antenna is sized for Earth coverage, 50 cm diameter.

- Antenna efficiency is assumed to be 50%
- Antenna gain is computed to be 15.6 dBi
- Line loss is an estimation based on satellite implementation
- Satellite transmit power is 100 W, with 3 dB output backoff and 1.5 dB line loss
- Total satellite *EIRP* is calculated based on satellite antenna gain and power
- *EIRP* per carrier is the total satellite *EIRP* divided by the number of carriers

Propagation Parameters are as described for the forward uplink, except the user link frequencies are at L-band.

User Terminal Parameters inputs are given for the three user terminal types. Gain is calculated from size and an assumed 55% efficiency. Line loss is dB for the semi-fixed and fixed user terminals.

- Received Carrier Level at Receiver input (C) is calculated
- Receiver C/N_o and available E_b/N_o are calculated
- Data Rate—input to assess bandwidth considering modulation and coding
- Available downlink E_b/N_o is calculated
- End-to-end E_b/N_o combines the uplink and downlink E_b/N_o
- The required E_b/N_o to close the link is obtained from GMR-1 G3 waveforms numbers
- 3 dB margin is desired at this stage of design. The handheld case just barely closes, with the 100 W satellite power being used for 4 carriers

At the bottom of the link budget, the carrier bandwidth is given along with the single user data rate and number of users per carrier. The total capacity is computed.

The number of simultaneous users is adjusted (if possible) to have 3-dB margin. Number of users affects the downlink only, where the users share the satellite power.

The handheld user terminal end-to-end link closes for only 16 users or 40 kb/s capacity. The semi-fixed terminal user forward link closes with 680 simultaneous users and 1.7 Mb/s capacity. The fixed user forward links has 1.66 Mb/s capacity. Note that the return and forward total capacities are not the same.

16.4.1.4 *Use of Steerable Spot Beam Antennas on Satellite*

The previously presented forward and return link budgets used fixed, Earth-coverage satellite antennas for the user and gateway links and did not support handheld user terminals. Use of a 1.6 m L-band antenna (versus the 0.50 m Earth coverage antenna) with 8 deg beamwidth

Table 16web-4. Return Link Budget: Comparison of Cases for Handheld Users.

SCS Return Link Cases	Units	SCS Earth	SCS Spot	GEO Spot	Comments and references	
User Uplink frequency	GHz	1.62	1.62	1.62	L-band uplink	Given
User terminal type		Handheld	Handheld	Handheld		
Diameter	m	0.08	0.08	0.08		Input
Beamwidth	deg	162.0	162.0	162.0		
Gain	dBi	0.1	0.1	0.1	Assume 55% efficiency	
Power	W	1	1	1		Input
Backoff and line loss	dB	0.0	0.0	0.0		Assumed
User EIRP	dBW	0.1	0.1	0.1		
Propagation range	km	26,000	26,000	39,000		Given
Space loss	dB	-184.9	-184.9	-188.5		
Atmospheric losses	dB	-0.4	-0.4	-0.4		
Fade margin	dB	-3.0	-3.0	-6.0	More fade margin for GEO	Given
Net path loss	dB	-188.3	-188.3	-194.9		
Satellite antenna, type		Earth cover	Steer spot	Fixed spots		
Diameter	m	0.50	1.60	7.00	GEO has 64 spots	Input
Beamwidth	deg	26.8	8.1	1.9		
Gain	dBi	15.6	25.7	38.5	Assume 50% efficiency	
Line loss on satellite	dB	-1.5	-1.5	**-2.0**		Assumed
Received carrier power, C	dBW	-174.2	-164.1	-158.3		
Sys.noise temp	dB-K	27.3	27.3	27.3		Assumed
Effective G/T, satellite	dB/K	-13.2	-3.1	9.2		
Receiver C/No	dB-Hz	27.1	37.2	43.0		
User Data rate	dB-Hz	34.0	34.0	36.0		
Available Eb/No, uplink	dB	**-6.9**	3.2	7.0		
SAT-GW Downlink freq.	GHz	6.90	6.90	4.20	C-band downlink	Given
Satellite antenna type		Earth cover	Earth cover	Fixed spot		
Diameter	m	0.15	0.15	2.10		Input
Antenna beamwidth	deg	26.8	26.8	2.4	26.8 deg Earth	
Antenna gain	dBi	15.6	15.6	36.3	Assume 50% efficiency	
Satellite transmit power	W	20	**5**	**100**		Input
Backoff and line loss	dB	-5.0	-5.0	-5.0	3 dB BO, 2 dB line loss	Assumed
EIRP, satellite	dBW	23.6	17.6	51.3		
EIRP per carrier	dBW	33.6	-7.5	3.2		
Propagation range	km	26,000	26,000	38,000		Given
Space Loss	dB	-197.5	-197.5	-196.5		
Atmospheric losses	dB	-1.5	-1.5	-1.5		
Net path loss	dB	-199.0	-199.0	-198.0		
Gateway terminal type		Tracking	Tracking	Tracking		
Diameter	m	7.0	7.0	9.0		Input
Beamwidth	deg	0.4	0.4	0.6		
Gain	dBi	51.5	51.5	49.4	Assume 55% efficiency	
Line loss	dB	-2.0	-2.0	-2.0		Assumed
Receive carrier power, C	dBW	-115.9	-157.0	-147.4	Single carrier	
System noise temperature	dB-K	26.0	26.0	26.0		Assumed
G/T, gateway	dB/K	25.5	25.5	23.4		
Receiver C/No	dB-Hz	86.7	45.6	55.2		
User Data rate	dB-Hz	34.0	34.0	36.0		
Available Eb/No, downlink	dB	52.7	11.6	19.2		
End-to-end Eb/No	dB	-6.9	2.6	6.7	Uplink plus downlink	
Required Eb/No	dB	-0.5	-0.5	2.8	GMR-1 3G waveforms	
Link Margin	dB	**-6.4**	**3.1**	**3.9**	3 dB goal	Given
Carrier bandwidth	kHz	31.25	31.25	31.25		Given
User data rate	kb/s	2.5	2.5	4.0		Input
Users per carrier		4	4	4		Given
No. simultaneous carriers		0	320	64,000		Input
No. simulataneous users		0	1,280	256,000		
Total bandwidth	MHz	0.00	**10.00**	2,000	Limited to 10 MHz for SCS	Output
Total capacity	Mb/s	**0.00**	**3.20**	**1,024**	Maximize	Output
Link closes?		**No**	**Yes**	**Yes**		

Table 16web-5. Forward Link Budget: Comparison of Cases for Handheld Users.

SCS Forward Link Cases	Units	SCS Earth	SCS Spot	GEO Spot	Comments and references	
Uplink frequency	GHz	5.100	5.100	5.900	C-band uplink	Given
Gateway terminal type		Tracking	Tracking	Tracking	2 GW ant. for 2 sats.	
Diameter	m	7.0	7.0	**9.0**		Input
Beamwidth	deg	0.6	0.6	0.4		
Gain	dBi	48.9	48.9	52.3	Assume 55% efficiency	
Transmit power	W	100	200	200		Input
Backoff and line loss	dB	-5.0	-5.0	-5.0	3 dB BO, 2 dB line loss	Assumed
EIRP, gateway	dBW	63.9	66.9	70.3		
EIRP per carrier		57.8	51.4	35.8		
Propagation range	km	26,000	26,000	39,000		Given
Space loss	dB	-194.9	-194.9	-199.7		
Atmospheric losses	dB	-5.0	-5.0	-5.0	Atmosphere	
Net path loss	dB	-199.9	-199.9	-204.7		
Satellite antenna, type		Earth cover	Earth cover	Spot		
Diameter	m	0.15	0.15	2.10		
Beamwidth	deg	26.8	26.8	1.7		
Gain	dBi	15.6	15.6	39.3	Assume 50% efficiency	
Line loss on satellite	dB	-1.5	-1.5	-1.5		Assumed
Received carrier power, C	dBW	-128.0	-134.4	-131.1		
System noise temp	dB-K	27.3	27.3	27.3		Assumed
G/T, satellite	dB/K	-13.2	-13.2	10.5		
Receiver C/No	dB-Hz	73.3	66.9	70.2		
User Data rate	dB-Hz	34.0	34.0	36.0		
Available Eb/No, uplink	dB	39.4	32.9	34.2		
Downlink frequency	GHz	1.52	1.52	1.52	L-band downlink	Given
Satellite antenna, type		Earth cover	Steer spot	Fix spots		
Diameter	m	0.50	1.60	7.00		Input
Antenna beamwidth	deg	26.8	8.6	2.0		
Antenna gain	dBi	15.6	25.1	37.9	Assume 50% efficiency	
Satellite TX power	W	100	100	**6,400**	64 spots at GEO	Input
Backoff and line loss	dB	-4.5	-4.5	-4.5	3 dB BO 1.5 dB line loss	Assumed
EIRP, satellite	dBW	31.1	40.6	71.5		
EIRP per carrier	dBW	25.1	25.2	37.0		
Propagation range	km	26,000	26,000	39,000		Given
Space Loss	dB	-184.4	-184.4	-187.9		
Atmospheric losses	dB	-0.4	-0.4	-0.4		
Fade margin	dB	-3.0	-3.0	-6.0	Clear view by fixed users	Given
Net path loss	dB	-187.8	-187.8	-194.3		
User terminal type		Handheld	Handheld	Handheld		Given
Diameter	m	0.09	0.09	0.09		
Beamwidth	deg	162.5	162.5	162.5		
Gain	dBi	0.0	0.0	0.0	Assume 55% efficiency	
Line loss	dB	0.0	0.0	0.0		Assumed
Receive carrier power	dBW	-162.7	-162.6	-157.3	Single carrier	
System noise temperature	dB-K	29.5	29.5	29.5		Assumed
G/T, user terminal	dB/K	-29.5	-29.5	-29.5		
Receiver C/No	dB-Hz	36.4	36.5	41.8		
User Data rate	dB-Hz	34.0	34.0	36.0		
Available Eb/No, downlink	dB	2.4	2.5	5.8		
End-to-end Eb/No	dB	2.4	2.5	5.8	Uplink plus downlink	
Required Eb/No	dB	-0.5	-0.5	2.8	GMR-1 3G waveform	
Link Margin	dB	**2.9**	**3.0**	**3.0**	3 dB goal	Given
Carrier bandwidth	kHz	31.25	31.25	31.25		Given
User data rate	kb/s	2.5	2.5	4.0	Single user (4/carrier HH)	Input
Users per carrier		4	4	4		Given
No. simultaneous carriers		4	35	2,800		Input
No. simulataneous users		16	140	11,200		
Total bandwidth	MHz	0.13	1.09	87.50		Output
Total capacity	Mb/s	**0.04**	**0.35**	**44.80**	Maximize	Output
Link closes?		**Yes**	**Yes**	**Yes**		

would close the uplink from handheld users. Link budgets, return and forward, are presented for handheld user terminals for three cases:

1. Earth coverage antenna on SCS satellite [same as previous case 1 where the return link did not close, and the forward link barely closed]
2. Spot beam antenna on SCS satellite [links close]
3. Spot beam antenna on GEO satellite [links close, large capacity]

Table 16web-4 shows the return link budget and Table 16web-5 shows the forward link budget for handheld user terminal cases. The first two cases are for the SCS satellite. The third case is included for reference to show what a dedicated single GEO satellite with 7 m unfurlable antenna and 64 fixed spot beam over the Earth could do.

For the return link, the first thing to notice is that in the "SCS Earth" case, the handheld link does not close because of the insufficient performance of the user-to-satellite link. The handheld user terminal has an *EIRP* of 0 dBW, and the SCS satellite Earth coverage antenna has *G/T* of –13 dB/K. The resultant uplink E_b/N_o is –6 dB which is lower than the required E_b/N_o of –0.5 dB. The downlink only adds more degradation.

The "SCS Spot" case has 10 dB higher satellite *G/T* and the return uplink closes. The downlink is sufficiently strong to support multiple simultaneous carriers. Since there can be nine separate spots, there can be 4 times frequency reuse if the traffic is spread out over the Earth. If all the traffic goes to one beam, then the indicated total bandwidth of 10 Mhz must be available to utilize full capacity (1280 users).

The "GEO Spot" case refers to a dedicated payload in GEO orbit. A 7 m satellite antenna at L-band with 64 fixed spot beams of approximately 2 deg size cover the Earth. This case can service a very large number of users (256,000 for return and 11,200 for forward), in this case with 4 kb/s voice versus 2.5 kb/s voice for the "SCS Spot." There can be a frequency reuse factor of seven, and depending on implementation as many as 25% of the users can be in a single beam.

For the forward satellite-to-user link (Table 16web-5), the "SCS Earth" just closes with only 16 users, and the "SCS Spot" closes with 140 users a 2.5 kb/s. The "GEO Spot" has much greater capacity with 11,200 users at 4 kb/s.

The GEO Spot Alternative Solution, Fig. 16web-1, is a potential solution which would satisfy the mission requirements, however it is a radical departure to the original spacecraft (Chap. 14) mission design concept and allocation to the payload design.

The alternative solution is a dedicated satellite providing two-way connection with hand-held or laptop sized terminals. The satellite has implemented a high satellite *G/T* with an 18 m unfurlable antenna and phased array feeds. The low bandwidth mobile channels allow for commandable beamforming either on board or a ground based processing implementation. The resultant satellite can be part of a hybrid terrestrial network, supporting a full commercial business plan. The concept of disaster relief would be a preemptable service to provide full coverage to hand held mobile phones.

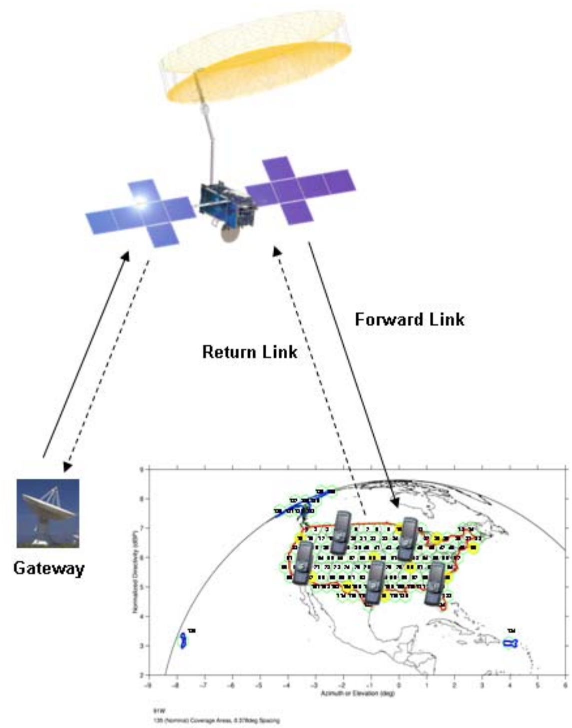

Fig. 16web-1. GEO Spot Alternative Solution.

16.4.1.5 Intersatellite Link Budget, Ka-Band (not updated)

Even though we have removed the two intersatellite (ISL) link antennas from the SCS payload, the ISL budget is presented for comparison. A high frequency, 32 GHz at the ITU designated frequency is used to minimize antenna size. Two 0.50 m antennas are required, one for each of the other two SCS satellites.

For this example, 5 W of spacecraft HPA power is used for each ISL to achieve a link capacity of 0.5 to 8 Mb/s at the 47,000 km range (assuming three equally spaced satellites in the 21,000 km altitude orbits). A margin of 9 dB is used to reduce the degradation of the user to satellite to satellite to gateway return path (and the equivalent gateway to satellite to satellite to user forward path).

16.4.2 FireSat II

Firesat is a LEO satellite with a remote sensing payload, and a 830 km altitude, 98.7 deg inclination, sun-synchronous orbit. The satellite would have a 101.3 minute period and repeats its ground track every 24 hours. The satellite mission is to gather data over the Earth's land mass of biomass burning, every day for five years.

Table 16web-6. Intersatellite Link Budget, Ka-Band.

		Link cases (GMR-1 3G)			
Item	Units	Hand held	Vehicle	Semi-fixed	Comments
Intersatellite link					
Frequency	GHz	32.00	32.00	32.00	Ka-band
Crosslink tx antenna					
Size	m	**0.50**	0.50	0.50	
Beamwidth	deg	1.3	1.3	1.3	
Efficiency	%	**55%**	55%	55%	
Gain	dB	41.9	41.9	41.9	Calculation
Crosslink transmit power	W	5	5	5	Input
Crosslink power	dBW	7.0	7.0	7.0	Input
Transmit backoff	dB	-3.0	-3.0	-3.0	Input
Line loss	dB	-2.0	-2.0	-2.0	Input
Crosslink EIRP	dBW	43.9	43.9	43.9	Calculation
No. simultaneos carriers		800	32	8	
Carrier bandwidth	kHz	31.25	31.25	62.50	
Users per carrier		4	4	1	Fixed by modulation / coding
Total number of users		3200	128	8	
EIRP per carrier		14.84	28.82	34.84	
Total bandwidth	MHz	25.0	1.0	0.5	
Propagation losses	km	47,000	47,000	47,000	
Space Loss	dB	-216.0	-216.0	-216.0	
Other losses	dB	0.0	0.0	0.0	
Net path loss	dB	-216.0	-216.0	-216.0	
Crosslink RX antenna, dia.	m	0.50	0.50	0.50	Fixed coverage
Beamwidth	deg	1.3	1.3	1.3	21,000 km, 26.8 deg
Efficiency	%	60%	60%	60%	
Gain	dB	42.3	42.3	42.3	Calculation
Line loss on satellite	dB	-1.0	-1.0	-1.0	
Received carrier power, C	dBW	-159.9	-145.9	-139.9	
Sys.noise temp	dB-K	26.0	26.0	26.0	
Effective G/T (satellite)	dB/K	15.3	15.3	15.3	
Noise					
Boltzmann's constant	dBW/Hz-K	-228.6	-228.6	-228.6	
Noise density, No	dBW/Hz	-202.6	-202.6	-202.6	
Receiver C/No	dB-Hz	42.7	56.7	62.7	
Data rate	kb/s	**2.5**	**21.0**	**64.0**	Single user
Data rate	dB-Hz	34.0	43.2	48.1	
Available Eb/No	dB	8.7	13.5	14.7	
Reqd. Eb/No (coding)	dB	**-0.5**	4.5	5.3	
Margin	dB	**9.17**	**8.97**	**9.35**	

Table 16web-7 gives the Firesat sensor instrument parameters, a mass of 20 kg and power of 80 W. Of main interest to the communications payload design is the average data rate of 10 Mb/s coming from the sensor. The sensor is estimated to be active from 60 deg S to 65 deg N latitudes, over land masses, and to be actively producing data 20% of the time averaged over 24 hours. Since the satellite in not in view of a ground station at all times, there must be data storage on the satellite, with high data rate transmission to the ground station(s) when in view.Due to the 830 km altitude orbit, the satellite is only in view of a given ground station for around ten minutes at one time. Due to transmission impairments of the atmosphere, we set a minimum satellite elevation angle of 10 deg as viewed from the ground station. The corresponding ground station off-nadir angle, as viewed from the satellite, is 60 deg, and the slant range is around 2,400 km. The coverage area radius on the ground is around 2,200 km. Since the satellite orbital period is 101.3 minutes, the satellite will be in view of the ground station for 11 minutes.

For an active sensor average data rate of 10 Mb/s over 20% of the 24-hr day, this implies 288 min of download time at 10 Mb/s. For a single ground station with 20-minutes view time per day, this would require a downlink of 144 Mb/s. These numbers are preliminary, and depend on sensor data rate, sensor duty cycle, and number of ground stations used to download data. For our link calculations, a 100 Mb/s downlink data rate is used.

Table 16web-7. FireSat II Sensor Instrument Parameters.

Parameter	Value	Comment
Aperature	0.12 m	Why make it any larger than necessary
Telescope f/#	5.5	Nice and slow... Helps optics designers sleep aty night
Detector Element Size	474 µm	Relatively large, but ok—standard fare for LEO environment imagers
Focal Plane Assemly Size	0.8 cm (track) × 1.0 cm (scan)	I prefer to spread the bands out a bit to minimize cross track. Scan direction could be quite a bit smaller, if we didn't have those pesky filters
Size	48 × 22 × 18 cm3	Nice and small—might have to grow in one dimension to avoid vignetting—may need a small electronics box somewhere
Mass	20 kg	I'm being generous here. My quick calculations suggests mass is actually close to 10–15 kg
Power	50 W	Will probably need another 10 W peak power, depending on how fast you want to cool down. I think this is close to the real number—possibly a bit on the high side, which makes up for the SMAD III number which was ridiculously low. If we were negotiating to build a real system, I'd ask for 80 W to make sure everyone is happy at system delivery
Data Rate	10 Mbps	Scales with number of bands... put in some margin
Mapping	1 GSD	We'll see...

The Firesat downlink budget is given in Table 16web-6. The frequency band selected is the X-band space-to-ground Earth remote sensing band at 8.2 to 8.4 GHz. The data rate is 100 Mb/s with QPSK modulation. Two cases are shown:

- Fixed nadir-pointing horn which requires 35 W power
- Electronically steerable planar phased array antenna with 1 W power

The link closes with either case, but the fixed horn has low gain and requires 35 W power versus 1 W power with the 25 cm steerable array. The steerable array will be less efficient in terms of power.

Different code rates are used for the two cases. In an effort to reduce power, the fixed horn case uses a 0.50 rate code which requires more bandwidth, but reduces the required E_b/N_o by 3 dB to 1.0 dB. The higher gain planar array case uses 0.90 rate code which requires less bandwidth but a higher E_b/N_o of 4.0 dB.

Note that the nadir-pointing planar array antenna has an additional 3 dB loss in gain at an angle of 60-degrees from the nadir direction due to its projected area at the 60 deg angle.

Atmospheric loss margin is assumed to be 5.5 dB for X-band links through the atmosphere at an apparent satellite elevation angle of 10 deg. Gateway system noise temperature is also affected by the low elevation angle.

A 10 m gateway terminal is assumed, perhaps with a radome to keep wind from mispointing the antenna, even though the antenna would most likely be autotracked.

Table 16web-8. Intersatellite Link Budget, Ka-Band.

FireSat Downlink Cases	Units	Fixed horn	Planar array	Comments
FireSat Downlink freq.	GHz	8.2	8.2	X-band
Data rate	Mb/s	100	100	Single carrier
Code rate		0.50	0.90	
Bandwidth	MHz	134	74	QPSK, 1.34x alpha
FireSat antenna type		Fixed horn	Planar array	Cover +/-60-deg from nadir
Diameter	m	0.02	0.25	
Antenna beamwidth	deg	120	10.2	
Antenna gain	dBi	2.6	24.0	Assume 55% efficiency
Gain reduction factor	dB	0.0	-3.0	Planar array @ 60-deg angle
Transmit power	W	35	1.0	Input
Backoff and line loss	dB	-3.0	-3.0	1 dB backoff, 2 dB line loss
EIRP, satellite	dBW	15.0	18.0	Satellite
Propagation range	km	2,400	2,400	slant range, 830-km altitude
Space Loss	dB	-178.3	-178.3	
Atmospheric losses	dB	-5.5	-5.5	Gaseous and rain margin
Net path loss	dB	-183.8	-183.8	
Gateway terminal type		Tracking	Tracking	Down to 10-deg elev angle
Diameter	m	10.0	10.0	May need radome for pointing
Beamwidth	deg	0.26	0.26	
Gain	dBi	56.1	56.1	Assume 55% efficiency
Line loss	dB	-2.5	-2.5	
Receive carrier power, C	dBW	-115.2	-112.2	Single carrier
System noise temperature	dB-K	27.3	27.3	Tracks to near horizon
G/T	dB/K	28.8	28.8	
Receiver C/No	dB-Hz	86.1	89.1	
Data rate	dB-Hz	80.0	80.0	
Available Eb/No	dB	6.1	9.1	
Modem loss	dB	-2.0	-2.0	QPSK
Required Eb/No	dB	1.0	4.0	Required to close link
Margin	dB	**3.1**	**3.1**	Need at least 3 dB margin