# Cost Model of Satellite Systems for Real-Time Helicopter Operations

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## 1. Introduction

Wireless communication has entered its fastest growth period in history since development of technologies provide wide spread deployment [4]. Real-time wireless information management in energy and resource operations requires fast and seamless information flow for data acquisition, management and operational decisions. Applications related to current location often need to send and receive data continuously. In geophysical surveys in remote areas, equipment movement by using helicopter to geophone locations as well as dynamic real-time information exchange between the pilot, base station and main office is necessary to guide the helicopter to the right location successfully and efficiently [1]. These tasks can be accomplished by wireless mobile telephone (cell phone), radio modems or satellite communication link. In most cases, using radio modems is less expensive and more convenient since cell phone coverage may not be available. The disadvantage of using radio modems is that the maximum range of communication using commonly available licensed radios (with a 5 to 40 watt transmitter) is limited to around 40 kilometers (with repeaters). A satellite communication link is an alternative choice in real-time geospatial operations [3][5].

## 2. Kodiak system review

Our research of the suitability of satellite communication links in geospatial operations is based on a system called Kodiak designed and built by Eagle Navigation System, Inc. of Calgary, Alberta for real-time mobile geospatial operations. The Kodiak system is primarily used for helicopter guidance and management during seismic survey operations. The system consists of two major components:

1) Kodiak Office software installed at a base station generates missions for the remote helicopters, displays the current helicopter positions, and provides reports on activities [2].

2) The NS500 Remote Guidance Unit (RGU) Kodiak navigation system installed in a helicopter communicates via radio frequency links with the base station, and provides real-time differential GPS signals along with continuous helicopter locations.

Further details of the Kodiak system are in [2], [3] and [5].

## 3. Cost model

The total cost *S* for one project involving one or more helicopters is a function of *d*, the number of operational days per project. The cost *S* (in Canadian dollars) is as follows:

$$S(d) = A + B + C + D \tag{3.1}$$

where *A* = satellite communication system cost, *B* = helicopter cost, *C* = company support cost, *D* = initial project setup cost.

There are three parts in cost *A*:

$$A(d) = A_1 + A_2 + A_3 \tag{3.2}$$

where $A_1$ = the satellite communication system cost in helicopter(s), $A_2$ = the satellite communication system cost at base station and $A_3$ = the satellite communication system cost at head office (only standard Internet connection is required at head office for Orbcomm satellite communication with helicopter(s) or base station). They are computed (in Canadian dollar) as follows:

$$A_1(s) = (1+T)\sum_{i=1}^{s}\left(R_{si}\left(M\left\lceil\frac{d_i}{31}\right\rceil + d_i\left(60C(h_i - y) + r(60h_i(2f)p - b)\right)\right) + R_{ei}d_i\left(\frac{E}{7} + \frac{G}{n}\right)\right) \tag{3.3}$$

$$A_2(d) = (1+T)\sum_{i=1}^{2}\left(R_{si}\left(M_i\left\lceil\frac{d}{31}\right\rceil + d\left(60C_i(h - y_i) + r(60h(2f)p - b)\right)\right) + R_{ei}d\left(\frac{E_i}{7} + \frac{G_i}{n}\right)\right) \tag{3.4}$$

$$A_3(d) = (1+T)\left(X\left\lceil\frac{d}{31}\right\rceil\right) \tag{3.5}$$

where *M* = monthly cost, *C* = air-time calling cost per minute, *h* = number of operational hours per day, *y* = free airtime in hours per day included in monthly fee**,** *r* = cost per byte additional to bytes included in monthly cost, *f* = number of message transmissions per minute at one direction (multiply by 2 for bi-directional transmissions), *p* = number of bytes of each message, *b* = daily free bytes included in monthly fee, *d* = number of total operational days per project, $d_i$ = number of operational days for satellite transceiver *i*, *E* = equipment weekly rental cost, *G* = equipment purchase cost, *X* = monthly fee of standard Internet access, *n* = number of days in capital period, *T* = tax rate, *s* = number of satellite transceivers, $R_{si}$ = currency exchange rate for service charge, $R_{ei}$ = currency exchange rate for equipment purchase and *i* = 1, 2, ….*s*.

The second cost $B$ of flying the helicopter is computed as follows (in Canadian dollars) and all elements are for an individual helicopter except $d$:

$$B(z) = (1+T)\sum_{i=1}^{z} d_i \left( Lh_i + Fh_i + Hh_i + I + Y \right) \tag{3.6}$$

where $L$ = hourly cost for hiring pilot(s), $F$ = hourly fuel cost, $H$ = hourly helicopter rental cost, $I$ = daily insurance cost, $d_i$ = number of days of flying helicopter $i$, $h_i$ = number of daily hours of flying helicopter $i$, $Y$ = daily maintenance cost and $i$ = 1, 2, ….$z$.

Assuming that a commercial company carries out a seismic survey project operation, equation for calculating the third cost $C$ of the commercial company support (in Canadian dollar) is

$$C(m) = (1+T)(d)\left( Q + \sum_{i=1}^{m} h_i (P_i) \right) \tag{3.7}$$

where $P_i$ = the individual commercial company's hourly personnel cost for person $i$, $Q$ = the commercial company's daily equipment cost, $d$ = number of working days, $h_i$ = number of daily working hours for person $i$, $m$ = the number of employees and $i$ = 1,2,…$m$.

The cost $D$ of initial setup for one project has three parts as follows:

$$D(k) = D_1 + D_2 + D_3 + wU \tag{3.8}$$

where $D_1$ = the initial setup cost in helicopter(s), $D_2$ = the initial setup cost at the base station, $D_3$ = the initial setup cost at head office, $U$ = cost to set up one repeater station for radio modems and $w$ = number of repeater stations. They are computed (in Canadian dollars) as follows:

$$D_1(k) = (1+T)\left( \sum_{i=1}^{k} \left( I_i + V_i R_i \right) \right) \tag{3.9}$$

$$D_2 = (1+T)\left( \sum_{j=1}^{2} \left( J_j + V_j R_j \right) \right) \tag{3.10}$$

$$D_3 = (1+T)K \tag{3.11}$$

where $I_i$ = the installation cost for helicopter $i$, $V_i$ = the activation cost of satellite transceiver/radio modem $i$ in helicopter, $J_j$ = the installation cost for satellite transceiver/radio modem $j$ at the base station, $V_j$ = the activation cost of satellite transceiver/radio modem $j$ at the base station, $K$ = the installation cost at head office, $k$ = number of satellite transceivers/radio modems in helicopter(s), base station or head office, $R$ = currency exchange rate for activation fee, $i$ = 1,2,…$k$ and j = 1 or 2 as only two satellite transceivers are likely for the base station.

## 4. Communication systems comparison

In this section we compare several different satellite transceivers using Iridium, Orbcomm, Globalstar and MSAT systems with elements in equations (3.3), (3.4), (3.9) and (3.10).

In Table 4.1 *M* is monthly cost, *C* is air-time calling cost per minute, *y* is free airtime in hours per day included in monthly fee, *G* is equipment purchase cost and *V* is the activation fee (all prices in Table 4.1 are in Canadian dollars unless they are indicated by “US$”.). Further technical details for satellite systems are given in Appendix I.

Table 4.1 Comparison of communication system costs and latency

| Satellite system | | M | C | r | y | G | V | Latency |
|---|---|---|---|---|---|---|---|---|
| Iridium * | Motorola 9500 | US$19.95 | US$0.68 | $0 | 0 | $1,440 | US$20 | Data over dial-up: 800 ms round trip; data over Direct Internet Data: 5-10 s to 5 -10 min |
| | Motorola 9505 | | | | | $2,395 | | |
| | SatTalk II | | | | | US$4,495 | | |
| | Airsat I | | | | | US$29,995 | | |
| GlobalStar | Qualcomm GSP 1600 | $365 | $1.39 per additional minute | $0 | 0.2 | $1,495 | $50 | voice: 900 ms |
| MSAT | ST211 Land Mobile Satphone | US$39.99 | US$0.99 | $0 | 0 | US$2,300 | US$50 | 500 ms |
| Orbcomm | Technisonic OSAT-100& SkyTrac | $70 for 5,000 bytes | $0 | $0.015 | 0 | US$8,495 + US$800 for antenna | $95 | less 60 s to 90 minutes |
| | Panasonic KX-7101 | $0 | $0 | $0.015 | 0 | US$725 | $95 | less than 60 s to 90 minutes |
| | Magellan GSC-100 | US$29.95 | $0 | $0 | 0 | US$850 antenna included | US$49.95 | 5 to 90 minutes |
| | Stellar ST-2500 | US$29.95 | $0 | $0 | 0 | US$335 + US$45 for antenna | US$49.95 | 5 to 90 minutes |
| | Quake1200 | $0 | $0 | $0.0036 78 | 0 | US$ | $50 | less than 60 s to 90 minutes |
| Radio modem | Pacific Crest 35 watt | $0 | $0 | $0 | 0 | US$1,900 | | 10 ms |

* Variation of Iridium satellite product prices is large due to different designs and functions. Details are in Appendix III.

## 5. Cost model for high accuracy helicopter seismic survey

Iridium satellite communication system is used between helicopter and base station in high accuracy helicopter seismic survey since the Iridium system has low system latency. The communication between base station and head office is carrying project information for which low latency is not a critical requirement. Thus, Orbcomm system with higher system latency and lower update rate, which is more cost-effective, is adopted in communication between base station and head office.

We assume the seismic survey field site is in Alberta at 57 degrees north and one helicopter with one satellite transceiver installed is deployed. Two satellite transceivers are installed at base station, one for helicopter transmission (Iridium) and one for head office communication (Orbcomm). A standard Internet connection is used at head office to communicate with base station.

The cost $A_1$ for the Iridium system is calculated using equation (3.3) (all prices in Canadian dollar) assuming that $M$ = US\$19.95, $d = d_1 = 10$, $C$ = US\$0.68, $h_1 = 6$, $r = 0$, $T = 0.07$, $R_{s1} = 1.60$, $R_{e1} = 1$ and $s = 1$.

With the assumption that the satellite transceiver is purchased, $E = 0$, $y = 0$, $G$ =\$1,440 and $n = 450$, i.e.

$$A_1(1) = (1+0.07)\sum_{i=1}^{1}\left(1.60\left(19.95\left\lceil\frac{10}{31}\right\rceil + 10(60(0.68)(6-0)+0)\right) + 1(10)\left(\frac{0}{7}+\frac{1{,}440}{450}\right)\right)$$
$$= \$4{,}259.37. \tag{5.1}$$

Assuming Kodiak path files (76 bytes each) are transmitted bi-directly every 5 minutes by Orbcomm satellite transceiver, transmission frequency per minute $f = 0.2$ and each message size $p = 76$ bytes. The cost $A_2$ for base station with one Iridium satellite transceiver and one Orbcomm satellite transceiver is calculated using equation (3.4) with additional assumptions for Orbcomm of $M$ = \$0, $r$ = \$0.003678, $C$ = \$0, $E = 0$, $y = 0$, $G$ =US\$1,150, $R_{s2} = 1$ and $R_{e2} = 1.60$. This gives

$$A_2(10) = (1+0.07)\left(\begin{array}{l}\left(1.60\left(19.95\left\lceil\frac{10}{31}\right\rceil + 10(60(0.68)(6-0)+0)\right) + 1(10)\left(\frac{0}{7}+\frac{1{,}440}{450}\right)\right)\\ + \left(\begin{array}{l}1\left(0\left\lceil\frac{10}{31}\right\rceil + 10(60(0)(6-0) + 0.003678(60(6)2(0.2)76) - 0)\right)\\ + 1.60(10)\left(\frac{0}{7}+\frac{1{,}150}{450}\right)\end{array}\right)\end{array}\right)$$
$$= \$4{,}733.82. \tag{5.2}$$

We assume $X$ = \$30.00. The cost $A_3$ of standard Internet access at head office to communicate with Orbcomm satellite transceiver at base station is calculated using equation (3.5) as

$$A_3(10) = (1+0.07)\left(30.00\left\lceil\frac{10}{31}\right\rceil\right) = \$32.10. \tag{5.3}$$

Iridium costs were obtained from Infosat Telecommunications and Preferred Communication. Prices for Orbcomm equipments and services were obtained from Quake Global Inc. and Rom Communication (see Appendix III and IV).

Total satellite communication cost is calculated using equation (3.2):

$$A(10) = \$4{,}259.37 + \$4{,}733.82 + \$32.10 = \$9{,}025.29. \tag{5.4}$$

Cost element $B$ of flying Bell 205 helicopter is calculated using equation (3.6) with the assumption that $d_i = 10$, $L = 0$, $F$ = \$350, $H$ = \$2,500, $I = 0$, $M = 0$, $z = 1$ and $T = 0.07$. The costs $L$, $I$ and $M$ are all zero as the hourly helicopter cost $H$ includes pilot cost, basic insurance cost and maintenance cost. Assuming that the number of operational hours per day $h_i = 6$, we have

$$B(1) = (1+0.07)\sum_{i=1}^{1}((10)(0(6)+350(6)+2{,}500(6)+0+0)) = \$182{,}970.00 \quad (5.5)$$

The rate for helicopter (Bell 205) rental service was obtained from Helicopter Transport (Canada) Services (see Appendix II).

Cost $C$ is computed using equation (3.7). Company personnel chargeout rate is between \$72.92 per hour and \$125.00 per hour with the assumption of 150 annual working days. Assuming the commercial company's daily equipment cost $Q$ = \$600, $h$ = 8 operational hours per day and $m$ = 2 employees, one at personnel chargeout rate of \$72.92 per hour and one at \$125.00 per hour, we have

$$C(1) = (1+0.07)(10)(600+(8)(72.92+125.00)) = \$23{,}361.95. \quad (5.6)$$

With assumption of $I_1$ = \$2,500 and $V_1$ = US\$15, $k$ = 1 and $R_1$ = 1.60, cost $D_1$ for helicopter is calculated as follows:

$$D_1(1) = (1+0.07)\left(\sum_{i=1}^{1}(2{,}500+15(1.60))\right) = \$2{,}700.68. \quad (5.7)$$

For the Iridium satellite transceiver ($j$ = 1), we assume $J_1$ = \$5,000, $V_1$ = US\$15 and $R_1$ = 1.60. And the Orbcomm satellite transceiver ($j$ = 2) costs are $J_2$ = \$5,000, $V_2$ = \$50 and $R_2$ = 1. This gives a base station setup cost $D_2$

$$D_2 = (1+0.07)((5{,}000+15(1.60))+(5{,}000+50(1))) = \$10{,}779.18. \quad (5.8)$$

At head office we have $K$ = \$2,000 for standard Internet connection setup, cost $D_3$ for head office is

$$D_3 = (1+0.07)(2{,}000) = \$2{,}140.00. \quad (5.9)$$

The total initial setup cost $D$ is calculated using equation (3.8). $w$ = 0 since we assume that no radio modem is used in the project. Thus we have

$$D(1) = \$2{,}700.68+\$10{,}779.18+\$2{,}140.00+\$0 = \$15{,}619.86. \quad (5.10)$$

When the satellite transceiver is purchased, the total cost $S$ of one 10-day high accuracy seismic survey project is

$$S(10) = \$9{,}025.29+\$182{,}970.00+\$23{,}361.95+\$15{,}619.86 = \$230{,}977.10. \quad (5.11)$$

## 6. Cost model 1 for forest fire operation (Iridium Internet connection)

In forest fire operations, high accuracy transmission is not necessary. The Orbcomm system is used in the helicopters. Since the necessary Internet access is not available at the base station, helicopters communicate with the base station via head office. In forest fire cost model 1, helicopters send data to head office. Head office then transfers the data to an Iridium ground gateway via an Internet connection. From the Iridium ground gateway there are two choices for data transmission to an Iridium satellite phone at the base station: (a) Dial-Up Data (2,400 bps) or (b) Direct Internet Data (10,000 bps). Data rates for both Iridium data services are high enough for transmission of KFP files (assuming each KFP file is 76 bytes and 15 transmissions per minute for each helicopter, a resultant 190 bytes per second assuming 10 helicopters are transmitting simultaneously). Dial-Up Data has a lower latency (on the order of 200 ms as it uses a voice circuit) while Direct Internet Data has a higher data rate and higher latency (which could by up to 10 minutes as shown in Table 4.1). The extra bandwidth of the Direct Internet Data connection could be used to carry transmissions besides KFP files (e.g. text E-mail messages). Further technical details are in Appendix III.

We assume the operation field site is in Montana at 50 degrees N with 60 second (or less) Orbcomm system latency. We also assume 10 helicopters are deployed in one operation, 5 for the full 10 operational days, 3 for 6 operational days and 2 for 2 operational days. Each helicopter has one Orbcomm satellite transceiver installed. One Motorola 9500 Iridium satellite phone is used at base station. Figure 6.1 shows the communication connections of cost model 1 for forest fire operations.

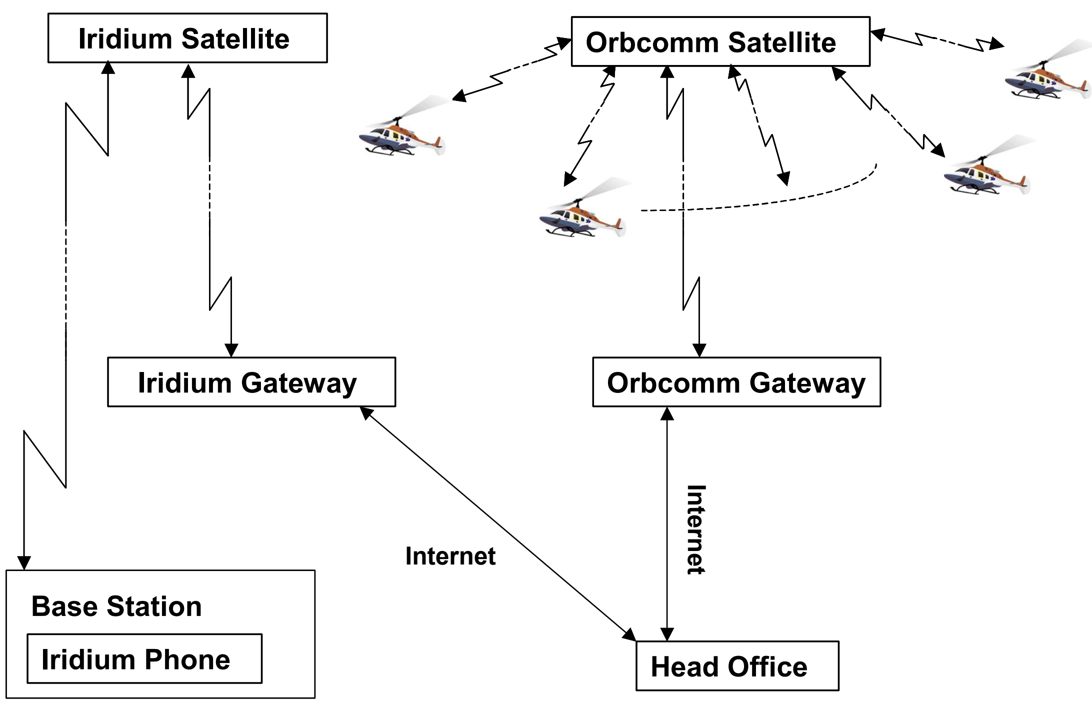


Figure 6.1 Communication connections for cost model 1 (Iridium plus Orbcomm) of forest fire operations.

The cost $A_1$ for the satellite communication system is calculated using equation (3.3) with assumption of $M$ = \$0, $C$ = US\$0, $h_i$ = 6, $r$ = \$0.003678, $f$ = 0.2, $p$ = 76, $T$ = 0.07, $R_{si}$ = 1, $R_{ei}$ = 1.60 and $s$ = 10. Assuming that the satellite transceiver is purchased, $E$ = 0, $y$ = 0, $G$ = US\$1,150 and $n$ = 450, i.e.

$$A_1(10) = (1+0.07)\sum_{i=1}^{10}\left(\begin{array}{l} 1\left(0\left\lceil \frac{10}{31}\right\rceil + d_i\left(60(0)(6-0) + 0.003678\left(60(6)2(0.2)(76) - 0\right)\right)\right) \\ +1.60(d_i)\left(\frac{0}{7} + \frac{1{,}150}{450}\right)\end{array}\right)$$

$$= \$3{,}416.02. \qquad (6.1)$$

where $d_1$ to $d_5$ = 10, $d_6$ to $d_8$ = 6 and $d_9 = d_{10}$ = 2 for different helicopter operational days.

The cost $A_2$ for the base station with one Iridium satellite transceiver is as follows:

$$A_2(10) = (1+0.07)\sum_{i=1}^{1}\left(1.60\left(19.95\left\lceil\frac{10}{31}\right\rceil + 10(60(0.68)(6-0)+0)\right) + 1(10)\left(\frac{0}{7}+\frac{1{,}440}{450}\right)\right)$$
$$= \$4{,}259.37. \qquad (6.2)$$

The cost $A_3$ for head office is calculated using equation (3.5) as follows:

$$A_3(10) = (1+0.07)\left(30.00\left\lceil\frac{10}{31}\right\rceil\right) = \$32.10. \qquad (6.3)$$

Total satellite communication cost is calculated using equation (3.2) as

$$A(10) = \$3{,}416.02 + \$4{,}259.37 + \$32.10 = \$7{,}707.49. \qquad (6.4)$$

In forest fire operation cost element $B$ of flying 10 helicopters (assumed to be a Bell 206B) is calculated using equation (3.6). We assume that $d$ = 10, $h_i$ = 6, $L$ = 0, $F$ = \$114, $H$ = \$795, $I$ = 0, $M$ = 0, $z$ = 10 and $T$ = 0.07. The costs $L$, $I$ and $M$ are all zero as the hourly helicopter cost $H$ includes pilot cost, basic insurance cost and maintenance cost.

$$B(10) = (1+0.07)\sum_{i=1}^{10}((d_i)(0(6)+114(6)+795(6)+0+0)) = \$420{,}176.16. \qquad (6.5)$$

where $d_1$ to $d_5$ = 10, $d_6$ to $d_8$ = 6 and $d_9 = d_{10}$ = 2 for different helicopter operational days.

The rental rate information for Bell 206B helicopter can be seen in Appendix II from Delta Helicopters Ltd.

Cost $C$ is the same as cost $C$ of high accuracy seismic survey in section 5:

$$C(2) = (1+0.07)(10)(600+(8)(72.92+125.00)) = \$23{,}361.95. \qquad (6.6)$$

The cost $D_1$, $D_2$ and $D_3$ for the satellite communication system are computed as follows:

With the assumption of $I_i$ = \$2,500 and $V_i$ = \$50, $k$ = 10 and $R_i$ = 1, cost $D_1$ for 10 helicopters is calculated as follows:

$$D_1(10) = (1+0.07)\left(\sum_{i=1}^{10}(2{,}500+50(1))\right) = \$27{,}285.00. \qquad (6.7)$$

Assuming base station setup cost of one Iridium satellite transceiver $J_1$ = \$5,000, $V_1$ = US\$15 and $R_1$ = 1.60, cost $D_2$ for a base station is calculated as follows:

$$D_2 = (1+0.07)(5{,}000+15(1.60)) = \$5{,}375.68. \qquad (6.8)$$

Initial setup cost $D_3$ for head office is calculated as follows:

$$D_3 = (1 + 0.07)(2{,}000) = \$2{,}140.00. \tag{6.9}$$

We assume $w = 0$ since no radio modem is used in the project. Total initial setup cost $D$ is calculated as follows using equation (3.8).

$$D(10) = \$27{,}285.00 + \$5{,}375.68 + \$2{,}140.00 + \$0 = \$34{,}800.68. \tag{6.10}$$

The total cost $S$ for model 1 of one forest fire operation with Iridium Internet connection is

$$S(10) = \$7{,}707.49 + \$420{,}176.16 + \$23{,}361.95 + \$34{,}800.68 = \$486{,}046.28. \tag{6.11}$$

where the predominant cost (86.4%) is for helicopter flying time.

## 7. Cost model 2 for forest fire operation (all Orbcomm communications)

In the 2nd forest fire operational model, every component in system connection is kept the same as model 1 in section 6 except the connection between head office and base station. An Orbcomm satellite transceiver is used at base station instead of an Iridium satellite phone. After receiving data from helicopters, the head office transfers data to the base station through the Orbcomm system and vice versa. Figure 7.1 shows the communication connection of this forest fire operational model.

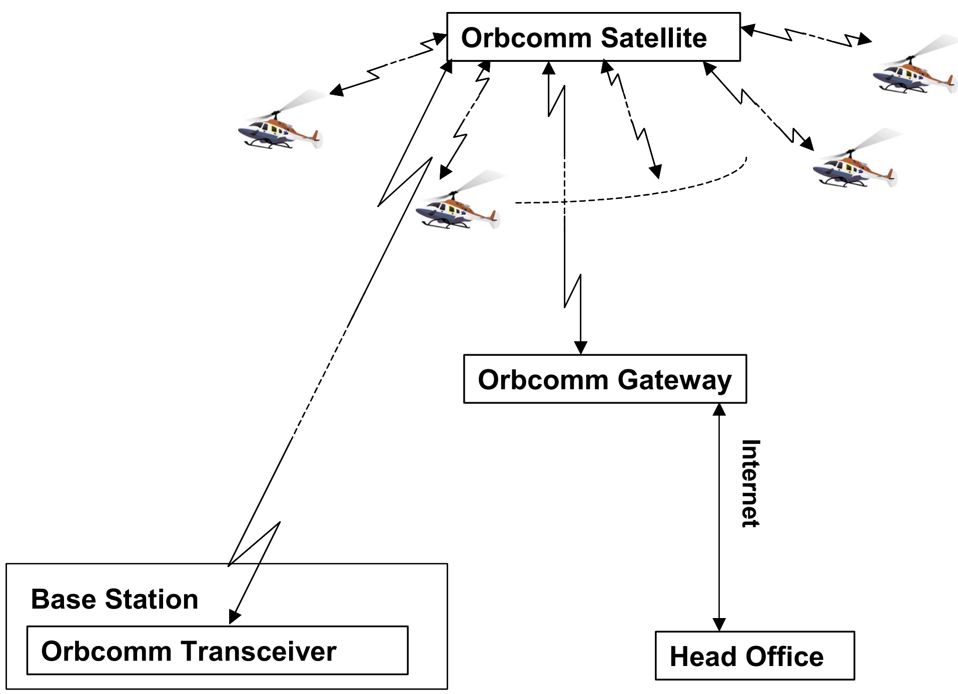


Figure 7.1 Communication connections for cost model 2 of forest fire operations (all Orbcomm).

The cost $A_1$ for the Orbcomm satellite communication in helicopter is the same as $A_1$ in section 6 as

$$A_1(10) = (1+0.07)\sum_{i=1}^{10}\left(\begin{array}{l} 1\left(0\left\lceil\frac{10}{31}\right\rceil + d_i\left(60(0)(6-0)+0.003678(60(6)2(0.2)(76)-0)\right)\right) \\ +1.60(d_i)\left(\frac{0}{7}+\frac{1{,}150}{450}\right)\end{array}\right)$$

$$= \$3{,}416.02. \tag{7.1}$$

where $d_1$ to $d_5 = 10$, $d_6$ to $d_8 = 6$ and $d_9 = d_{10} = 2$ for different helicopter operational days.

The cost $A_2$ for the base station with one Orbcomm satellite transceiver is as follows:

$$A_2(1) = (1+0.07)\left(\begin{array}{l} 1\left(0\left\lceil\frac{10}{31}\right\rceil + 10\left(60(0)(6-0)+0.003678(60(6)2(0.2)76-0)\right)\right) \\ +1.60(10)\left(\frac{0}{7}+\frac{1{,}150}{450}\right)\end{array}\right) = \$474.45. \tag{7.2}$$

The cost $A_3$ for head office is calculated the same as $A_3$ in section 6:

$$A_3(10) = (1)(1+0.07)\left(30.00\left\lceil\frac{10}{31}\right\rceil\right) = \$32.10. \tag{7.3}$$

Using equation (3.2) total satellite communication cost is calculated as follows:

$$A(10) = \$3{,}416.02 + \$474.45 + \$32.10 = \$3{,}922.57. \tag{7.4}$$

Cost $B$ and $C$ are unchanged as cost $B$ and $C$ of model 1 in section 7:

$$B(10) = (1+0.07)\sum_{i=1}^{10}\left((d_i)(0(6)+114(6)+795(6)+0+0)\right) = \$420{,}176.16. \tag{7.5}$$

where $d_1$ to $d_5 = 10$, $d_6$ to $d_8 = 6$ and $d_9 = d_{10} = 2$ for different helicopter operational days.

$$C(2) = (1+0.07)(10)(600+(8)(\$72.92+\$125.00)) = \$23{,}361.95. \tag{7.6}$$

In initial setup cost $D$ elements $D_1$, and $D_3$ are also not changed. Only $D_2$ is calculated based on Orbcomm cost elements using equation (3.10). They are

$$D_1(10) = (1+0.07)\left(\sum_{i=1}^{10}(2{,}500+50(1))\right) = \$27{,}285.00. \tag{7.7}$$

$$D_2 = (1+0.07)(5{,}000+50(1)) = \$5{,}403.50. \tag{7.8}$$

$$D_3 = (1+0.07)(2{,}000(1)) = \$2{,}140.00. \tag{7.9}$$

Total initial setup cost $D$ is calculated as follows using equation (3.8).

$$D(10) = \$27{,}285.00 + \$5{,}403.50 + \$2{,}140.00 + \$0 = \$34{,}828.50. \tag{7.10}$$

The total cost $S$ of one forest fire operation in model 2 with all Orbcomm connections is as follows

$$S(10) = \$3{,}922.57 + \$420{,}176.16 + \$23{,}361.95 + \$34{,}828.50 = \$482{,}289.18. \tag{7.11}$$

Since all connections in model 2 are using Orbcomm system, latency in data transmission could be higher than model 1 with an Iridium satellite phone at the base station. The total cost in model 2 is approximately \$3,803 less due to the absence of per minute charges for the Iridium data connection to the base station. The major cost is still the cost of flying the helicopters.

## 8. Cost model example of high accuracy seismic survey with radio modems

In this example, we assume that radio modems are used between helicopter and base station, and Orbcomm system is used between base station and head office. We assume 2 radio repeaters have been built to relay the radio transmission.

The cost $A_1$ is \$0.00 since there is no transmission cost with radio modem.

The cost $A_2$ for one Orbcomm system at the base station is as follows:

$$A_2(1) = (1+0.07)\begin{pmatrix} 1\left(0\left\lceil \frac{10}{31} \right\rceil + 10\left(60(0)(6-0) + 0.003678\left(60(6)2(0.2)76 - 0\right)\right)\right) \\ +1.60(10)\left(\frac{0}{7} + \frac{1{,}150}{450}\right) \end{pmatrix} = \$474.45. \tag{8.1}$$

Using equation (3.5) we calculate satellite communication cost of Orbcomm system at head office as follows:

$$A_3(10) = (1)(1+0.07)\left(30.00\left\lceil \frac{10}{31} \right\rceil\right) = \$32.10. \tag{8.2}$$

Total satellite communication cost is calculated using equation (3.2):

$$A(10) = \$0 + \$474.45 + \$32.10 = \$506.55. \tag{8.3}$$

Assuming Bell 205 helicopter is used cost elements $B$ is calculated the same as $B$ in section 5 using equation (3.6).

$$B(1) = (1+0.07)\sum_{i=1}^{1}\left((10)(0(6) + 350(6) + 2{,}500(6) + 0 + 0)\right) = \$182{,}970.00. \tag{8.4}$$

Equation (3.7) gives the calculation of commercial company support cost C as

$$C(2) = (1+0.07)(10)(600+(8)(72.92+125.00)) = \$23{,}361.95. \qquad (8.4)$$

With assumption of $I_1$ = \$2,500 and $V_1$ = \$0, $k$ = 1 and $R_1$ = 1, cost $D_1$ for helicopter is calculated using equation (3.9) as follows:

$$D_1(1) = (1+0.07)\left(\sum_{i=1}^{1}(2{,}500+0(1))\right) = \$2{,}675.00. \qquad (8.6)$$

We assume $J_1$ = \$5,000, $V_1$ = \$50, $R_1$ = 1 for one Orbcomm satellite transceiver ($j$ = 1) and $J_2$ = \$5,000, $V_2$ = \$0, $R_2$ = 1.60 for one radio modem at base station. Using equation (3.10) cost $D_2$ for the base station is calculated as

$$D_2 = (1+0.07)((5{,}000+50(1))+(5{,}000+0(1))) = \$10{,}753.50. \qquad (8.7)$$

At head office, only an Internet connection is required to communicate with the base station Orbcomm transceiver. Thus, $K$ = \$2,000 and $R$ = 1 and setup cost $D_3$ for head office is

$$D_3 = (1+0.07)(2{,}000(1)) = \$2{,}140.00. \qquad (8.8)$$

With the assumption of repeater cost $U$ = \$1,600 and $w$ = 2 total initial setup cost is

$$D(1) = \$2{,}675.00+\$10{,}753.50+\$2{,}140.00+\$1{,}600(2)(1.07) = \$18{,}992.50. \qquad (8.9)$$

When we purchase the satellite transceivers, the cost S of one high accuracy seismic survey with two radio modems is

$$S(10) = \$506.55+\$182{,}970.00+\$23{,}361.95+\$18{,}992.50 = \$225{,}831.00. \qquad (8.10)$$

## 9. Conclusions

As we can see the Orbcomm satellite system is less expensive. In fact, cost component $A$ (satellite communication system cost) is about 10 times less for Orbcomm compared to Iridium. And availability of Orbcomm satellite transceiver OEM board provides user interface for customized application integration. Technisonic Industries Ltd. of Mississauga, Ontario, Canada is using Orbcomm satellite system for communication between helicopter and base station (see Appendix V). However Orbcomm has a much higher latency and lower update rate than Iridium. When real-time accuracy is a major concern in the seismic survey project such as communication between helicopter and base station in high accuracy seismic survey, Iridium is the only choice to handle continuous real-time data transmission using satellite link.

## 10. References


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## Appendix I Satellite system technical details

| Satellite system | Orbit | Transmitter service band | Data rate | One-way propagation delay in ms (min, max) |
|---|---|---|---|---|
| Iridium (LEO) | 66 active satellites, 780 km altitude, 6 orbital planes | 1616.0 - 1626.5 MHz transmit, 1616.0 - 1626.5 MHz receive | 2,400 bps sustained, up to 10,000 bps burst with "Direct Internet Data Service" | (2.6, 8.2) |
| Orbcomm (LEO) | 35 active satellites, 16 satellites inclined at 45˚ with respect to the equator and 17 inclined at 70˚ /108˚ at a 825 km altitude | Uplink: 148.0 – 150.05 MHz downlink: 137.0-138.0 MHz | Transmit: 4800 bps at 137 - 138 MHz and 400.05 – 400.15 MHz. | 2.7 |

| Satellite system | First launched | Range | Current market | Comments |
|---|---|---|---|---|
| Iridium (LEO) | First: 1997, commercial service starts in 1998. 8 years designed satellite life | Global | Aviation, construction, disaster relief/emergency, government, leisure travel, maritime and media. | Short Message Service (up to 120 characters) available soon. Iridium Satellite LLC funded by a group of private investors is current owner of Iridium (Nov,2000). Iridium has contracted with the Boeing Company to operate and maintain the satellite constellation. Motorola continues to provide subscriber equipment on commercially acceptable terms. |
| Orbcomm (LEO) | First: 1991, 4th launch in 2000, 4 year designed satellite life | Global near continuous between the polar circles | Product Link System of Caterpiller Inc in Europe, Asia, S/N America. Ocean vessel track and control of Posdata Co. Ltd in Korea. Avionics weather in Garmin Intl and EcoFlight | Orbcomm filed for 'Chapter 11' bankruptcy protection in Sept 2000 and new owner is Orbcomm LLC (Aug, 2001) after International Licensees LLC purchased the business. |

| Satellite system | Orbit | Transmitter service band | Data rate | One-way propagation delay in ms (min, max) |
|---|---|---|---|---|
| GlobalStar (LEO) | 48 active satellites, 1,410 km altitude, 8 orbital planes | 2483.5 - 2500.0 MHz transmit, 1610.0 - 1626.5 MHz receive | 7,200 bps sustained | (4.6, 11.5) |
| MSAT (GEO) | Geostationary 36,000 km altitude 106.5°W | 1530-1559 MHz transmit 1631.5-1660.6 MHz receive | 4,800 bps | (270, 400) |

| Satellite system | First launched | Range | Current market | Comments |
|---|---|---|---|---|
| GlobalStar (LEO) | 1999, designed satellite life: 7.5 years | Within +/- 68° latitude of the equator | High-quality voice, roaming, SMS, message waiting indicator, automatic mode selection, voice mail position location, packet-switched and asynchronous data. Customer: NBC, Italian Navy | Now has about 55,000 subscribers, laid off 175 people (~50%) in Aug. 2001. File bankruptcy in Nov, 2001. |
| MSAT (GEO) | Apr.20, 1996, designed satellite life: 12 years | North America, Central America, northern South America, Caribbean, Hawaii, up to 250 km offshore | Transportation, utility, oil & gas, government, maritime, and resource industries. Customers: Emergystat Ambulance Service Environment Canada Northstar, Ontario Hydro, N American Electrical Reliability Council, Schneider Trucking and Enduro racing. | TMI's MSAT-1 brings the benefits of telecommunications and information to areas without access to conventional land-based telecom networks and makes it. The satellite's on-board telecommunications payload is capable of handling thousands of simultaneous secure and reliable voice. |

## Appendix II Helicopter services rate

1. Delta Helicopters Ltd.

Box #1, Site #6, RR #1
St. Albert, Alberta, T8M, 1M8
Canada

Contact: Bruce Simpson

Phone: (800) 665 3564
(780) 984 6767
Email: bruce_s@telusplanet.net
Website: www.deltahelicopters.com

Basic rate for helicopter rental service of Bell 206B (carry 1 pilot and three passengers) is as follows (all prices in Canadian dollar):

Hourly rental service costs $795 including one pilot, maintenance cost and basic insured amount of 50 cents per pound of the cargo carried by the helicopter. Additional $114 is charged for fuel per hour for flying helicopter (May 08, 2002).

2. Helicopter Transport (Canada) Services

PO Box 250
Carp, Ontario, K0A-1L0
Canada

Contact: Murray Cheslock

Phone: 613-839-5868
Fax: 613-839-2976
Email: operations@htsc.ca
Website: http://www.htsc.ca

Basic rate for helicopter rental service of Bell 205 (1 pilot and 6 passengers) is as follows (all prices in Canadian dollar):

Hourly rental service costs $2,500 including one pilot, maintenance cost and basic insured amount of 50 cents per pound of the cargo carried by the helicopter. Additional $350 is charged for fuel per hour for flying helicopter (December 22, 2001).

## Appendix III Information and basic satellite cost elements for Iridium

With 66 active satellites in constellation Iridium Satellite provides global mobile satellite voice and data services with complete coverage of the Earth.

Iridium LLC filed bankruptcy in August 1999 and in November, 2000 Iridium Satellite LLC purchase the operating assets of Iridium LLC and its subsidiaries.

Iridium Satellite LLC is grouped by private investors including Baralonco NV of Netherlands Antilles (24.3%, controlled by Saudi Prince Khalid bin Abdullah bin Abdulrahman), Bareena Holdings Party Ltd of Australia (26.9%, owned by Michael Boyd), Milport Associates SA of Panama (8.9%, owned by Inepar, Brazil) and Syndicated Communications Inc of USA (26.9%, controlled by Herbert Wilkins). These four main shareholders hold 87% of Iridium Satellite LLC. Iridium Satellite LLC has contract with Boeing Company to operate and maintain Iridium satellite constellation and network. Motorola continues to be the major equipment supplier to Iridium under commercial acceptable terms. Iridium Satellite LLC has signed a USD72 million contract with US Department of Defense, under which 20,000 government employees will have unlimited use of airtime over the Iridium network [7][8].

Contact for Iridium:

Infosat Telecommunications

18 Fawcett Road
Coquitlam, BC, V3K 6X9
Canada

Contact: Preet Marwaha

Tel: (604) 524-3038/(800) 871-3011
Fax: (604) 524-6067
Email: pmarwaha@infosat.com
Website: http://www.infosat.com

Iridium system cost information from Infosat Telecommunications has the following elements (all prices in Canadian dollar):

Motorola 9500 satellite phone purchase price is $1,440 per unit. Rental service is also available with weekly rental rate of $149 per unit including 30 free minutes, adaptor, battery and charger.

Iridium data kit is also available at price of $369. Iridium data kit provides the hardware and software required to establish an Iridium data call with a Motorola 9500 or Motorola 9505 portable satellite phone. Iridium data kit includes data adapter and serial cable to provide connection to a Motorola 9500 or 9505 portable satellite phones. The most important part in Iridium data kit is Iridium World Data Services CD that contains all software and documentation required to install and configure Iridium World Data Services on computer.

Honeywell has developed Airsat 1 for Iridium system to provide reliable and high quality two-way satellite communications (voice only) for light aircraft over a single digital channel in Iridium's global satellite system (not support data transmission). Cost of Airsat 1 is US$29,995 including Airsat 1 transceiver unit, handset and specially designed Satcom Blade antenna. With its powerful RF output (6 watts, much higher 0.57 watts of Motorola 9500 and 9505) Airsat I is so far the best choice for communication under heavy blade rotation in aircraft. Installation fee for Airsat 1 is around US$20,000 (Stratos, Contact: Heather Griffin at heather_griffin@stratos.ca, May 06, 2002).

SatTalk II is another Iridium product for aircraft satellite communication in both voice and data. SatTalk II is developed by Icarus and used with a Motorola 9505 satellite portable phone. SatTalk II provides clear telephone communications and Internet access in aircraft cockpit and cabin. Price of SatTalk II is US$4,495 and Motorola 9505 satellite portable phone costs US$1,400 (Stratos, Contact: Heather Griffin at heather_griffin@stratos.ca, May 06, 2002).

Iridium "Dial-Up Data Service provides dial-up connectivity from a PC, through your Iridium satellite phone to another computer, a corporate network/LAN or an Internet Service Provider (ISP). This service offers a data rate of up to 2.4 Kbps" [10].

Roundtrip system latency for circuit switched Dial-Up data is approximately 800 ms. Most of this latency is made up of GSM processing time and only a few tens of milliseconds is due to propagation delay (Iridium, Contact: David Wigglesworth at david_wigglesworth@sat-services.com, May 14, 2002).

"Direct Internet Data Service provides connectivity from a PC, through your Iridium phone, directly to the Internet through dedicated servers at the Iridium gateway. This service utilizes transparent compression, resulting in a data rate of up to 10 Kbps, depending on content. (Graphics and images will result in lower throughput)" [10].

Iridium is currently developing Short Burst Messaging (SBM) services that will provide very low latency two-way messaging from small data messaging terminals (message size of 50-75 bytes). SBM service is targeted for unattended sensor, alarm and control applications [11], and is planned to start service in October 2002.  We learned from David Wigglesworth on May 10, 2002 that the SBM service requires the use of a new software data kit (not generally available until September 2002) and a Motorola 9522 L-Band transceiver (called a short burst data terminal.  SBM will NOT work with Motorola 9500 and 9505 Iridium telephones.

Short Burst Messaging data requires different AT Commands to Dial Up (circuit switched Data). Latency for Short Burst Messaging data messages from a mobile device to the Gateway in Arizona is expected to be in the order of ten seconds or less. Delivery of a short burst data message from one mobile device to another will incur at least double the single hop latency. Additional latency from Internet traffic routing of the message will apply. In fact mobile terminated messages will not be immediately delivered, but held in a Gateway mailbox until the mobile device either polls the Gateway or sends a message (Iridium, Contact: David Wigglesworth at david_wigglesworth@sat-services.com, May 14, 2002).

Different types of Iridium modems are available for satellite data transmission using modified the Motorola L-band transceiver (LBT). Price of 9500 Iridium Modem with Internal Subscribe Identify Module (SIM) Card Reader (CDM9500I35-I) is US$1000. In two kinds of ruggedized 9500 Iridium modems, modem A00002LA-E with external SIM Card Reader costs US$950 and modem A00002LA-I with internal SIM Card Reader costs US$2,500. The Iridium modems use Time Division Duplex as duplexing method, TDMA/FDMA as multiplexing method and have standard RS-232 (AT commands) interface. Average output power is from 0.60 W to 0.62 W (NAL Research Corporation at http://www.nalresearch.com, phone: 703-392-1136, e-mail: contact@nalresearch.com, May 23, 2002).

Service charges of using Iridium satellite system include activation fee of $60 and monthly fee of $38.95 per satellite transceiver. An additional airtime charge of $1.19 per minute applies for communication between Iridium Subscriber Units (ISU) and $1.99 per minute for communication between Iridium phone and non-Iridium phone (Infosat Telecommunications, May 09, 2002).

There are three different prepaid package services provided by Preferred Communications (Satstar). Package A with 100 prepaid minutes costs US$0.79 per minute from ISU to ISU with activation fee of US$25. Package B provides 500 prepaid minutes of US$0.72 per minute within ISUs and its activation charge is US$20. With 1000 minutes prepaid at US$0.68 per minute for communication from ISU to ISU, package C's activation fee is US$15. All three packages are valid for 12 months and monthly access fee for each package service is US$19.95. Remaining minutes can be rolled over to next year and each package includes free voicemail service. (Preferred Communications at www.satstar.com, phone: 800 300 6020, contact: George Sloan, email: george.sloan@satstar.com, May 30, 2002)

## Appendix IV Information and basic satellite cost elements for Orbcomm

Orbcomm provides global 2-way data services via low-Earth orbit (LEO) Satellites and ground infrastucture. Orbcomm currently has 35 satellites in orbit, and is licensed by the FCC to launch and operate up to 48 satellites. Orbcomm is designed for short packet ( .5 second) transmission.

Orbcomm filed for Chapter 11 bankruptcy protection in September 2000. In August 2001 International Licensees LLC, a consortium of Orbcomm licensees and affiliates, purchased business and assets of Orbcomm Global, L.P. and its other entities. The consortium includes OHB Systems GMBH, Orbcomm Asia Ltd. and other private investors. New company was named Orbcomm LLC. Hans E. W. Hoffmann, who has over 35 years of international experience in aeronautical and space engineering and satellite communications and has held a number of executive management positions in both technological and business development, was selected as Chief Executive Officer and President of Orbcomm LLC [6].

Contact for Orbcomm:

(a) Quake Global, Inc.

9765 Clairemont Mesa Blvd., Site A
San Diego, CA 92124
USA

Contact: Darrin Carlin

Tel: (858) 277-7290
Fax: (858) 277-7259
Email: dcarlin@quakeglobal.com
Website: www.quakeglobal.com

The Q1200 development kit from Quake Global, Inc. is designed for remote monitoring and control applications using Orbcomm system with better transmission frequency than Magellan GSC-100 and Stellar ST2500. Q1200 module combines high performance with price as low as cellular link and is the perfect solution for developers who need to integrate a satellite-based communications transceiver into customized applications. The Q1200 satellite transceiver unit included in the development kit provides two serial ports for communication with the host application. One serial port fully supports the Orbcomm Serial Interface Specification and the second port can be custom programmed to support application specific communications or used as a monitoring/debug port. Lower power consumption (12 volt +/- 10%) modes also offer additional flexibility for remote applications. The price of Quake Q1200 development kit is US$1,150 (May 23, 2002).

(b) Panasonic also produces satellite communicator using Orbcomm satellite system. The Panasonic KX-G7101 satellite communicator with GPS is available in current market. Price of Panasonic KX-G7101 (1 designates GPS service included.) varies from US$600 to US$725 per unit subject to purchase order size (Electronic Production Materials, Inc., Contact: Cindy Novak at epmpa@voicenet.com, October 5, 2001).

A new version Panasonic KX-G7201 is also available at price of US$625 per unit. SDK (Software Development Kit) for the KX-G7201 is available at a cost of US$2,200. OEM Board of Panasonic satellite communicator will not be in the market until January 2003. (Customer Support of Panasonic, Contact: Frank Orrow at OrrowF@PANASONIC.com, December 20, 2001)

Orbcomm service charges using Quake Q1200 is based on Orbcomm Message Unit (MU) and transmission frequency. Each MU is 25 bytes. Rate of each MU varies subject to different transmission frequency. For more than 2000 MU per month, cost of each thousand MU is $91.95 ($0.003678 per byte). Additional administrative fees apply for each transceiver unit including activation fee of $50, suspension fee of $20 and swap out fee of $10 (Rom Communications Inc. at www.romcomm.com, phone: 866 442 3762, contact: David Popowich at dave.poppwich@romcomm.com, May 22, 2002).

(c) Novotech Distribution

155 Terrence Mathews Crescent
Ottawa, ON, K2M 2A8
Canada

Contact: Beth Lewis

Tel: (800) 268 8628/(613) 280 1900 ext 279
Fax: (800) 366 0536/(613) 280 1917
Email: info@novotechdistribution.com
Website: http://www.novotechdistribution.com

Orbcomm system cost information from Novotech Distribution has the following elements:

Magellan GSC-100 equipment purchasing price is US$850 per unit including choice of antenna: root mount, truck mount and magnetic mount. Rental rate is US$100 per week.

Magellan GSC-100 development kit is also available at US$995 per kit with one Magellan's Satellite Modem OEM Board. This price includes Satellite Modem OEM board, power supply interface Boards, choice of fixed or mobile antennas, data-power cable extension, AC power adapter, satellite PC software, evaluate® software, interface cables and user manual and reference guide.

Magellan GSC-100 development kit is loaded with unique development software that provides full serial port access, and remote polling capability, while still supporting its screen and keyboard features. Magellan GSC-100 development kit can be used and integrated with Magellan's OEM board for system development (http://www.magellangps.com/frames/frame_wireless.htm, January 29, 2002).

The Magellan's OM200 OEM board is designed to allow low-cost two-way communication between your equipment and the Orbcomm satellite system. It provides maximum flexibility to the OEM developer. Price for single OM200 OEM board is US$525 (http://www.navtechgps.com/supply/om200.asp, January 29, 2002).

Novotech Distribution bought assets of DCInextech, top Magellan products distributor in Canada on November 30, 2001. Former contact information of DCInextech is as follows:

DCInextech

1 Terrence Mathews Crescent
Kanata, ON, K2M 2G3
Canada

Contact: Doug Lalonde

Tel: (800) 268 8628/(613) 599 5095
Fax: (800) 366 0536/(613) 599 5064
Email: support@mysatmail.com
Website: http://www.dcinextech.com/www.mysatmail.com

(d) Besides Magellan products, Stellar ST2500 is another satellite transceiver using Orbcomm satellite system. ST2500 is a more reliable and cost effective new version of Stellar EL2000.

The price for the ST2000 is US$335 with additional US$75 for GPS. VHF antenna costs US$45 and a GPS antenna costs US$20.The price for the OEM board of ST2500 is US$320 (Steve Mazur at Stellar Satellite Communications, phone: (703) 234-4186 and email: steve@stellar-sat.com, March 21, 2002).

Charges of using Magellan GSC-100 and Steller ST2500 (sending message every 5 to 10 minutes) to subscribe service of Orbcomm satellite system include activation fee of US$49.95 and monthly fee of US$29.95 per satellite transceiver with unlimited airtime and message exchanges (Novotech, May 23, 2002).

Orbcomm service charge is the same for incoming and outgoing messages. Practical maximum Orbcomm message size is 2000 bytes. If message needs to be stored and then forwarded (Orbcomm globalgram service), each message can contains up to 229 characters and 182 characters for receiving message (Orbcomm at www.orbcomm.com, phone: 800 672 2666,
contact: Melanie Fiore at Fiore.Melanie@orbcomm.com, May 22, 2002).

## Appendix V Information of Technisonic Industries Ltd.

Technisonic Industries Ltd.

250 Watline Avenue
Mississauga, ON, L4Z 1P4
Canada

Contact: Robert Riel

Tel: (905) 890 2113
Fax: (905) 890 5338
Email: info@til.ca
Website: www.til.ca

Technisonic Industries Ltd. has focused its efforts on the development of aeronautical band VHF ground equipment and special mission airborne RF and audio communications systems. Communication with the Orbcomm satellites is through a VHF FM link. Follows are details of pricing of equipments and services:

The airborne approval OSAT-100 box (Using Panasonic 7101 board) used for communication with Orbcomm costs US$8,495 each and the recommended antenna (a Comant CI-2480 combined FM and GPS) costs US$800 each. Comant CI-2480 combined FM and GPS antenna can also be purchased from manufacturer at US$560 (FOB Dallas, TX). Alternative choice of antenna is CI-177 FM antenna with price at US$176 (FOB Dallas, TX) or US$123 (FOB Lansdale, PA). VHF/GPS Combined antenna CI-2480 costs US$560 (FOB Dallas, TX) (Dallas Avionics, Inc. (Comant), Contact: Clint, phone: 800 527 2581, http://www.dallasavionics.com/comant.html, February 21, 2002).

Satellite communication service is provided by SkyTrac Systems Ltd. (http://www.skytrac.ca/cs.htm) through an exclusive arrangement with Technisonic Industries Ltd. The service contract is summarized as follows (all prices in Canadian dollar):

1. $70.00 per month fixed cost (maximum of 5,000 bytes).

2. Additional per byte charge per subscriber communicator of $0.015.

3. Activation/deactivation fee per subscriber communicator of $95.00.

4. Provisioning change fee per request per subscriber communicator $30.00.

5. Activation of service requires five-business days notice to activate or deactivate or re-provision a satellite communication service.

Technisonic Industries Ltd. has about 40 systems now deployed in the field. Helicopter communication every three minutes using Orbcomm satellite communication through the FM antenna is very reliable.

Communication service of Orbcomm satellite through SkyTrac system has latency between the time a message sending from the helicopter to its arrival at the "base station" of typical two to three minutes. The OSAT-100 is designed for a fleet management process where positions of aircraft are reported back to a network control center to allow for automated tracking of flight time for maintenance (and billing) purposes.

The user interface of the OSAT-100 on the helicopter is now only available through a Palm Pilot, not a general-purpose computer. No experiment has been done with other approaches due to the required 1.5 years to get FCC aircraft installation approval for electronic devices in aircraft. Thus, sending messages to the OSAT-100 on the helicopter for use with the NS500 RGU is probably not feasible at this time (February 20, 2002).

SkyTrac has experimented with the Stellar boards, but is not successful to work in helicopters due to reliability problems. The system latency using SkyTrac system through Orbcomm varies at different region. At south of 65 degrees N, the system latency is usually less than 60 seconds. Between 65 and 75 degree. N, 10 to 15 minutes latency is expected. It is because that the satellite is not in view of a gateway on the ground even though it may be visible. The message must be stored on the satellite for forwarding to the gateway when one comes into view (March 21, 2002).

According information of Orbcomm official website, “the message delivery time (or "latency") depends on the specific hardware setup, message size and location of the remote unit. In the continental US, Orbcomm is committed to providing 90% in 6 minutes or less, and 98% in 15 minutes or less for all message traffic” [9].

## Appendix VI Information of MSAT

TMI Communications' geostationary MSAT (36,000 km orbit) provides telecommunications covering North America, Central America, northern South America, the Caribbean, Hawaii, and up to 250 miles offshore.

Fixed mobile antenna of MSAT satellite transceiver has size of broomstick and must point up. This makes installation on helicopter difficult. When helicopter tills, communication will have problem since antenna is set for particular latitude based on horizontal. Tracking antenna of MSAT transceiver has size of a small ball and costs more than fixed mobile antenna. MSAT satellite transceiver costs more than US$3,000 each (Personal Satellite Network, Inc. at www.skyhelp.net, phone: 800 590 2089, contact: Don Rickerson at don@skyhelp.net, May 23, 2002).

In November 2001, TMI Communications and the satellite division of Motient Corporation joined force to form a new entity, Mobile Satellite Ventures.