The PCsat Mission and Cubesat Design Notes

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Abstract

There are growing opportunities for Universities to gain educational
access to Space. The Naval Academy has used the Department of Defense
Space Test Program for its PCsat and Sapphire projects and the Stanford
Cubesat program offers a unique opportunity to get numerous small
student satellite payloads into space. As a spin-off of our PCsat
project, we have investigated several off-the-shelf solutions to the
Telemetry, Command and control portion of small satellites that can
greatly simplify small satellite and CubeSat designs. This permits
students to concentrate on the various payloads and other aspects of the
project without starting from scratch with a comm. system.

This simple comm. System based on AX.25 packet radio is being flown this
summer in the Naval Academy's Personal Communications Satellite (PCsat)
which will demonstrate downlinks receivable on Hand Held Transceivers
(HT's) with only a whip antenna. Further these simple downlinks can be
easily fed into the Internet for live worldwide distribution of data.
These designs are all based on the amateur radio standard on-air AX.25
packet network protocol that is implemented in a number of off-the-shelf
modems (called Terminal Node Controllers or TNC's). The following
paragraphs describe three such hardware devices and the remainder of
this paper describes how TNC's and the AX.25 protocol were used on
PCsat.

OFF-THE-SHELF AX.25 HARDWARE

One advantage of using the AX.25
protocol is that any node in the
system can be used for relaying
data between any other nodes.
Thus, the TNC can not only
provide the dedicated up and
downlinks and command/control
channels, but also serve as a
generic relay for other
applications on a secondary
basis. Examples of TNC's on
orbit are SAREX, SPRE, MIR, ISS,
SUNSAT, OPAL and soon to be
PCsat, SAPPHIRE and maybe future
STARSHINE's. Here are our
choices for AX.25 hardware:

The MIM Module

The simplest Telemetry module is
the one cubic inch MIM module
which provides for multiple
periodic AX.25 packets at 1200
baud AFSK containing up to 5
analog channels and 8 on/off
bits. Different rates can be set
for the BEACON, Telemetry, GPS
position and CW Identification.
The module has no command and
control capability, but that is
easily added with CTCSS or DTMF
receivers/decoders.

Photo 1. The MIM module. See http://www.toad.net/~wclement/bruninga/mic-lite.html

1200 Baud KPC-3+

The second and more capable telemetry is the use of a Kantronics KPC-3PLUS TNC which has the advantage of an AX.25 receiver and thus the ability to do command and control. It can even be carved down to fit within the four inch cube. The board will fit diagonally in a Cubesat if the connectors are removed and the power supply portion of the board is relocated

This gives the same Telemetry, Beacon, GPS and CW ID capability as with the MIM module, but includes a full TNC DIGIPEATER and 4 channel COMMAND/CONTROL channel as well. With the full TNC, a complete digital communications transponder mission, such as used on PCSAT, can be supported.

9600 Baud KPC-9612+

The 9612+ TNC adds a second comm. Port to the TNC offering one port at 1200 and the other at 9600 baud. The 9612+ offers the same 5 analog telemetry channels of the MIM module and serial port communications of other TNCs, but also gains a total of 8 configurable command or I/O bits, four ON/OFF command bits and one input bit. Because of the added 9600 baud comm. Port, the KPC-9612+ TNC was designed into the final PCsat design. PCsat is just one of a possible constellation of student built satellites supporting the ASTARS Mission all based on using AX.25 TNC's in orbit.

THE ASTARS MISSION

The ASTARS Mission is a generic mission (supported by any TNC in orbit) to provide real-time message, position, and status relay via satellite to a worldwide Internet linked amateur radio tracking system. Any amateur or university payload can support this mission by simply enabling the DIGIPEAT-ON function in any AX.25 compatible transponder (TNC). The users of such a relay system can be for Boats at Sea, remote environmental sensors, cross country travelers, expeditions, school projects, or any other travelers which are far from any existing APRS terrestrial tracking infrastructure.

The satellite downlink from such travelers or remote sites are fed into the existing worldwide Internet linked ground system by a few permanent ground stations. These APRS satellites would join our own PCsat, and other University built small satellites to provide connectivity to everyone involved in this mission providing connectivity to their birds while not locally in view..

The Space segment of PCsat/ASTARS has been demonstrated a number of times in space via MIR School

Bob Bruninga

tests, the Shuttle SAREX, the SPRE mission, AO-16, UO-22 and more recently via SUNSAT and ISS. The satellite concepts described herein would be operated under the rules of the Amateur Satellite Service and the rules of the FCC. Full details of the Cubesat concepts and the PCsat mission can be found at:

http://web.usna.navy.mil/~bruninga/cubesat.html
http://web.usna.navy.mil/~bruninga/astars.html

Photo 2. Personal Communications Satellite (PCsat) with Antennas

Photo 3. Personal Communications Satellite, PCsat and Design Team

The PCsat MISSION

The remainder of this paper will describe the design of a low cost easy to build APRS satellite to meet the need for mobile and handheld amateur satellite users. This APRS Satellite Mission is for worldwide real-time message and position/status data exchange between users and is in contrast to the mission and design of all existing amateur PACSATS that concentrate on message store-and-forward. Further, it incorporates the Internet as part of its design instead of trying to compete with it. Although the Naval Academy has been in dialog with a number of other satellite owners and designers over the last 7 years to accommodate these concepts into their designs as well (SAREX, SPRE, MIR, ASUsat, UO-22, and SUNSAT), PCsat will be the first satellite designed with APRS UI digipeating as the primary mission with these objectives:

1) Handheld/Mobile live digital tracking and communications in footprint
2) Worldwide handheld and mobile position and status reporting (via internet)
3) Handheld and Mobile message uplink to satellite (then to Internet)
4) Handheld and Mobile message downlink/delivery from Internet
5) Nationwide Bulletin delivery
6) Low Power GPS tracking of buoys, telemetry devices, wildlife, etc
7) Other UI digipeating applications
8) Worldwide one-line Emailing
9) School demonstrations and satellite lab activities

All of these mission objectives can be met with just a simple hardware TNC on orbit acting as a UI digipeater. Also, with the sophistication and added I/O of recent TNC's designed for APRS, the TNC itself can be the command and control system. Thus no additional on-orbit CPU's are required. Not only is the satellite hardware simple, but it can be reproduced by other satellite builders to help form a constellation of these relay satellites, all operating on the same frequency to give mobile users extended access beyond what is possible with one satellite alone. This concept of a Builders Channel for similar-mission spacecraft was presented at last years AMSAT Symposium [1].

BACKGROUND TO THE MOBILE SATELLITE NEED

Modern Technology is on the move. Satellite Wireless is the leading edge of technology. In the amateur satellite program, it should be a major driver for future amateur satellite missions. In just the last year there have been *many* hints at the future of Amateur Mobile and Handheld satellite communications.

1) Growing popularity of UI digipeating via MIR through 1999
2) Continuing high popularity of AO27 for handheld FM voice communications.
3) Activation of UO-14 for FM voice repeater mode in February 2000
4) Experimental UI digipeating via the UO-22 Satellite
5) FM VOICE repeating via SUNSAT SO-35 throughout 1999
6) Recent activation of SUNSAT SO-35 for UI and APRS
7) Recent Introduction of new TNC/Radios (Kenwood & Alinco)
8) Dayton 2000 introduction of the upgraded Kenwood TH-D7 data HT!

The potential of two-way satellite handheld text messaging (national paging) was serendipitously demonstrated at the Dayton Hamvention during a parking lot demo of the SUNSAT downlink. Due to a scheduling error, there was no success at the expected time so the HT was placed in a pants pocket and forgotten. But minutes later, the tale-tale beeping of the TH-D7 alerted me to an incoming APRS message and on inspection, it was a Bulletin from SUNSAT. Thus, amateur satellite message delivery to an un-attended obscured Handheld Transceiver was demonstrated.

Photo 4. Chas Richard, W4HFZ's mobile APRS Satellite capability (including HF). With an APRS Satellite, he can send and receive brief text messages anywhere on the planet a few times a day.

ASTARS

To identify this APRS satellite communications system from its terrestrial counterpart the space segment is called ASTARS for APRS Satellite Tracking and Reporting System which has evolved through a number of existing and previous satellite communications experiments. First was **1200 Baud PSK ASTARS** which was called TRAKNET [2] at the 1998 and 99 AMSAT conferences using AO-16, LO-19 and IO-26. It is a very viable capability for stations with PSK TNC's or using more recent sound-card modem uplink capability[3]. But it never became popular due to the rarity of PSK modems amongst most amateur satellite operators.

Satellite packet experiments using **1200 Baud AFSK ASTARS,** however, which *any* TNC can do, were demonstrated many times during experiments with the Space Station MIR[4] packet system and SAREX[5]. These experiments culminated in the June 1999 week long experiment via MIR which used the new Kenwood TH-D7 with built in 1200 and 9600 baud TNC's to demonstrate two-way self-contained APRS communications via

MIR at 1200 baud. During this test[6], over 55 stations conducted 2 way HT message communications.

Recently, experiments have been conducted with **9600 BAUD ASTARS** using UO-22 and SUNSAT and the new Kenwood 1200/9600 baud APRS data mobile radio, the TM-D700A [7]. This dual band data radio with built-in TNC's and front panel APRS displays made it possible to send and receive the very short APRS style communications via any 9600 Baud PACSAT with digipeat enabled (UO-22). Thus, the TM-D700 radio is an off-the-shelf satellite data terminal ready for ASTARS and it needs NO PC or other accessory. Kenwood also followed suit with 9600 baud upgrades to the TH-D7(G) HT with its internal front panel displays. Alinco also now sells another integrated TNC/Radio called the DR-135 which can also do both 1200 and 9600 baud built-in, though it needs an external Laptop to display the APRS data.

THE INTERNET

Unlike previous Amateur Satellite designs, APRS satellites can capitalize on the connectivity of the Internet instead of trying to compete with it. The Internet makes possible the linking together of multiple disparate downlink sites which allows a tremendous gain in reliability through space and time diversity reception. Instead of each station requiring their own downlink receiver and then only being able to hear packets within his own footprint, the Internet allows a few stations, called SAT-Gates (Satellite IGATES) to combine all packets heard into the existing worldwide APRS infrastructure (APRServe)[8] for delivery to any APRS operator anywhere.

APRS MESSAGES

     EMAIL :wb4apr@amsat testing delivery via pacsat from my van   en route to work.

For satellite operators unfamiliar with APRS messages, it should be understood that an APRS message is a single LINE of text. Most messages stand alone, but are occasionally strung together if it will not fit on one line. Photo 2 is a photo of a very brief 15 byte message received on the TMD700 radio. Messages from mobiles are usually quite brief as they must be entered on the Touch-Tone pad. But longer messages up to 64 bytes are routinely displayed.

Photo 5. The front panel of the TM-D700 showing an incoming 15 byte message (Messages can be longer up to 64 bytes).

EMAIL

Similarly, APRS can send and receive standard EMAIL messages via the worldwide internet linked APRServe system. This capability is limited, but very useful. The first limitation is that messages are only ONE LINE and the one line *includes* the full email address. This forces BREVITY! Secondly, although EMAIL can be originated under the control of the HAM sending it, EMAIL replies back from the Internet are only allowed via special Igates with operators that have volunteered to screen such traffic for 3rd party legality prior to being returned to RF. Here is an Email transmitted from my D700 mobile en route to work. Here is how it was entered into the D700:

Yet, here is how it was received by my Email system after being

SAT-Gated to APRServe and from there, picked up by the EMAIL Engine at WU2Z's and shipped out as regular Email:

Date: Mon, 7 Feb 2000 07:58:09 -0500 (EST)
From: WB4APR-9@unknown.net
To: wb4apr@amsat.org
Subject: APRS Message from WB4APR-9

USER GROUND STATION EQUIPMENT

To design an APRS satellite the link budget and capabilities of the users mobile stations must be well understood. The table below shows the uplink power and receiver antenna gains for all

USER Stations	ERP UHF (W)	ERP VHF (W)	Rcv UHF dBi	Rcv VHF dBi	Rcv STBY dBi	Applications
--------------	---	----	---	---	---	--------------------------
HANDHELDS	3	5	3	3	-6	Sailboats, Hikers, Wilderness
MOBILES	70	100	5	5	-6	Remote Travelers, Boats
HOME Stations	700	1000	13	13		Not intended for UPLINK

REQUIREMENTS/CONSTRAINTS DESIGN DRIVERS

To design a satellite to meet the HT/Mobile communications objective and the internet links as well, there are a number of factors involved in selecting the frequency band, antenna types, and baud rates for each of the mission objectives. First there

are a number of boundary conditions or assumptions:

1) Optimum ALOHA channel efficiency is about 20% due to collisions
2) VHF links have a 9 dB advantage over UHF links (omni to omni)

testing delivery via SUNSAT from my van en route to work.

Message received by MacAPRS IGate station WU2Z
Located in NO BRUNSWICK, NJ
APRS path = WB4APR-9>APK101,SUNSAT*:

participating stations in the ASTARS system. The column labeled Standby Receive Gain is for the user who is not aware of, nor optimized for satellite reception. For example, someone hiking with a HT in his pocket, or mobile parked under trees.

NETWORK Stations			
--------------	---	----	---
IGATE Receiver	7	5	Omni Internet receive site
MESSAGE NODE	70	100	Internet to user UPLINK site
COMMAND Station	700 1000	13 13	USNA

Although a wide variety of power and receiver gains are involved, these values are what form the basis of the APRS Satellite design and the architecture of the overall ASTARS System.

3) 1200 baud AFSK has a 7 dB advantage (measured) over 9600 baud FSK
4) T/R delays render 9600 only twice as fast as 1200 for APRS bursts
5) UHF uplinks require wideband Sat Rcvrs to avoid Doppler (- 4 dB)
6) UHF downlinks require user tuning during pass (not desired)

With these design drivers as a guide, the following are some of the first-order alignments of requirements to hardware. From these, then, the optimum trade-offs were made to arrive at the final PCsat design.

1) MSG delivery to HT in Standby requires best possible downlink (1200 baud VHF). Igate uplink is relatively unconstrained.
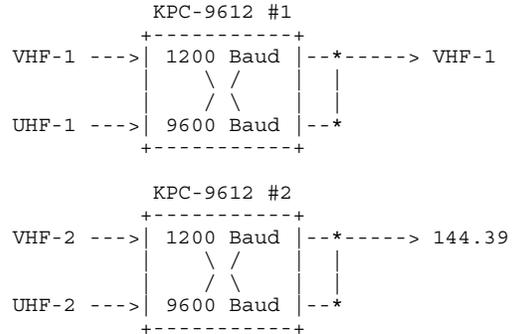2) MSG receipt from HT requires best possible uplink (1200 baud VHF).

3) Downlink to internet is relatively unconstrained.
4) Continent wide Bulletin Delivery requires existing 144.39 over USA and 1200 baud. The same for Europe will require a common European frequency too.
5) HT/Mobile real-time messaging requires same up/downlink & baudrates
6) GPS HT/Mobile tracking is relatively unconstrained.
7) Low power GPS tracking devices require best uplink (1200 baud VHF) and the uplink must not be used by any other satellite uplinks to avoid unintentional interference to other systems.
8) Other UI digipeating applications should be crossband full duplex and should use same up/downlink baud rates
9) Multiple uplink receivers to minimize collisions is desired.
10) Synchronizing of same-band downlink transmissions is desired to maximize the available half-duplex satellite receive time.
11) Redundancy and Backups are desired.
12) Bundling of packets in bursts amortizes individual TXDelays
13) UHF downlinks are of little value due to poor link budget and Doppler.
14) KISS Principle should reign. (Keep it Simple, Stupid)

HARDWARE ALIGNMENT TO REQUIREMENTS

Using the above criteria, PCsat was designed around two KPC-9612+ Dual Port TNC's. These TNC's have all the latest APRS generic digipeating advantages and can even cross route packets between ports. By using standard off-the-shelf TNC hardware and FIMRWARE, on orbit risk was minimized due to the track record of thousands of identical hardware in use all across the country for terrestrial APRS. Thus, the firmware is proven.

Each dual port KPC-9612+ can cross relay from either of its two inputs to its two outputs. With only two transmitters on VHF for best downlink budget, PCsat outputs both the 1200 and 9600 baud channels to the same transmitter, one for each TNC as shown below. PCsat uses a single VHF half-duplex channel in the ITU Satellite Subband for its

primary uplink and downlink, and one other unpublished VHF uplink. Similarly there are one published and one unpublished UHF uplink. For the unique APRS paging downlink over North America PCsat uses the dedicated 144.39 assignment to be able to send urgent messages from the satellite to travelers at any time who may only be monitoring the terrestrial APRS channel.

```
           KPC-9612 #1
          +-----------+
VHF-1 --->| 1200 Baud |--*-----> VHF-1
          |    \ /    |  |
          |    / \    |  |
UHF-1 --->| 9600 Baud |--*
          +-----------+

           KPC-9612 #2
          +-----------+
VHF-2 --->| 1200 Baud |--*-----> 144.39
          |    \ /    |  |
          |    / \    |  |
UHF-2 --->| 9600 Baud |--*
          +-----------+
```

FAILSAFE RESET

To recover from a SEU or other lockup condition in these commercial off-the-shelf TNCs, PCsat uses 3 methods of hardware resets back to launch defaults. First, each TNC has a failsafe RESET circuit that monitors the PTT of each TNC and as long as a transition occurs at least once a minute, then the TNC is assumed to be operating correctly and the TNC remains powered up. If there are no transmissions for over 1 minute, then a one-shot timer removes power from the TNC for 1 second to allow for a complete power up reset of the TNC.

Second, there is a 72 hour fail safe reset circuit that will reset both TNC's unless the counter is cleared by command from the ground at least once every 3 days. Third, a command bit in each TNC can be commanded to reset the other TNC.

TELEMETRY

Back in 1995 we defined the APRS 5 channel TELEMETRY format that

Kantronics subsequently has added to their "plus" TNC's. To make this usable on our satellite, the PCsat team added a 16 channel-to-four hardware multiplexer to allow telemetry to read as many as 16 values transmitted in four consecutive telemetry packets.

LINK BUDGET

The primary driver of this APRS Satellite design was to deliver messages to handhelds and mobiles with only whip antennas. For this, the downlink needed to be at least 12 dB stronger than most existing digital satellites. PCsat accomplishes this by taking advantage of the 9 dB link improvement of 2 meters compared to 70 cm and by using a 3 watt transmitter. Further, PCsat operates at a low transmit duty cycle unlike most existing PACSATS, because the Amateur Satellite population only covers 10% of the earths surface and with the low duty cycle of the ALOHA style of APRS operations, less than 4% of PCsat's average power budget is required.

```
 MISSION                    ELEMENT:
UPLINK     PATH    DOWNLINK
 ----------------------------------
---- ---------- ------ ----------
-
 HT Uplink of MSGS/POSIT to Internet
145.825@12  UIDIGI   145.825@12
 Live    HT-to-HT    Footprint   QSO's
145.825@12  UIDIGI   145.825@12

 Live    HT-to-Mobile    crosslinks
145.825@12  XBAUD    145.825@96
 Live    Mobile-to-HT    crosslinks
435.25 @96  XBAUD    145.825@12

 Mobile   uplink  of  MSGS/POSIT  to
Internet    435.25   @96    UIDIGI
145.825@96
```

Notice the advantage of incorporating the single North American Continent-wide coordinated APRS frequency into the downlink frequency plan. Although this frequency is in use by over 2000 users fulltime including over 600 wide area digipeaters, it is a well

Similarly, to conserve power and bandwidth, the 2 meter uplinks are reserved for only the low power handheld stations, or stand-alone tracking devices or data collection buoys or remote WX stations such as the one built by Ronald Ross, KE6JAB in Antarctica [9]. The mobiles and SATgates which have 35 to 50 watt transmitters will be asked to operate only on the UHF uplink frequencies where they can afford the more difficult link budget. The result is the further advantage of having spread out the user base over 4 uplink channels to minimize collisions.

CHANNEL USAGE AND MISSION SCENARIO

The following table maps the mission objectives into the various uplinks and downlinks on the satellite. It matches strengths and weaknesses of each mission area to the available link budgets and hardware:

```
 Live    Mobile-to-mobile    Footprint
comms        435.25  @96     UIDIGI
145.825@96

 Command    and    Control
ALL      MYRemote 145.825
 Other    UI    Applications
TBD      UIDIGI   145.825

 Low    power    Trackers
VHF2     UIDIGI   144.39 USA

 Nationwide    Message   delivery
UHF2@9600   MYgate   144.39 USA
 Nationwide    Bulletin   delivery
UHF2@9600   Mygate   144.39 USA
```

established universal frequency where ALL APRS operators can be found whether they are aware of a satellite pass or not. Actually, although 90% of the USA ham population is within range of this terrestrial infrastructure, 70% of the land mass is not so

travelers are often out of range of the terrestrial links.

Due to the shared use of 144.39 with the thousands of existing users, this downlink on 144.39 will ONLY be used for the special applications consistent with the national significance of this channel. Such applications might be getting an emergency or priority message to an existing APRS mobile no matter where he is; Infrequent Bulletins of National interest; Low power but high profile tracking of special devices, for example, the Olympic Torch. Due to the low duty cycle channel statistics of an ALOHA TDMA channel like APRS, even though the channel is in full use by thousands of users, still more than 50% of the time, the channel is "clear" as heard by any mobile anywhere at any instant.

SAT-GATE OPERATIONS

The Mobile-to-mobile and HT-to-HT communication missions work without any special considerations on the satellite or on the ground. But the more useful application is sending and receiving messages to any other APRS station worldwide by having the packets received by the SAT-Gates that are monitoring the satellite downlink and feeding every packet heard into the APRServe system. These SAT-Gates perform the following functions:

1) Monitor both downlinks and feed ALL packets into the Internet
2) Maintain a track on all Calls heard via satellite
3) Monitor the Internet and capture MESSAGES for these Calls
4) Deliver these messages at a "fair" rate under these conditions:
   a. The satellite is within 1400 km (above 30 deg) to mobile
   b. It sees "QRZ" in the Mobile's STATUS text or CUSTOM-3
   C. Deliver these messages until seen in the downlink 3 times

OMNI NO-TRACK SAT-GATES

Setting up a SATgate is trivial requiring nothing more than a normal packet station and omni antenna. Any APRS station can do it with existing software which contain the built-in Igate capabilities. Even if the station does not have horizon-to-horizon coverage, they are only contributing their packets to the same worldwide stream as all the other Igate receivers, so any station can help. Unlike any previous amateur satellite activity, PCsat will use the Internet to combine the outputs from a dozen such stations nationwide and the result is over a 99.96% chance of capturing every packet over the USA! Even if only 4 stations at any one time have the bird in view of their station and even if they only have a 60% chance of decoding each packet, their combined probability is 98%. But if the original packet is replicated TWICE, then this probability becomes 99.96%! A Certainty!

BASE STATION OPERATIONS

Since the APRS Satellites are shared assets with limited bandwidth, this message system should only be used by mobiles who have no other means to communicate from distant locations. For this reason, base station operations are not encouraged other than SAT-Gates or for direct contact with a mobile if needed. A Mic-E style packet from the D700 is only 9 bytes long, compared to a typical WinAPRS 80 byte position report. Thus, base station transmissions are discouraged.

SATELLITE TRACKING AND PASS PREDICTIONS

To help with satellite tracking for the casual and mobile user, Satellite tracking has been added to APRSdos in the form of APRStk.exe. When run within an existing APRSdos file structure (so you get all the maps and

other built-in-data), it presents the satellite predictions on the APRS map and will auto-tune the Kenwood radios including Doppler. It is available zipped up as a complete system for download from:
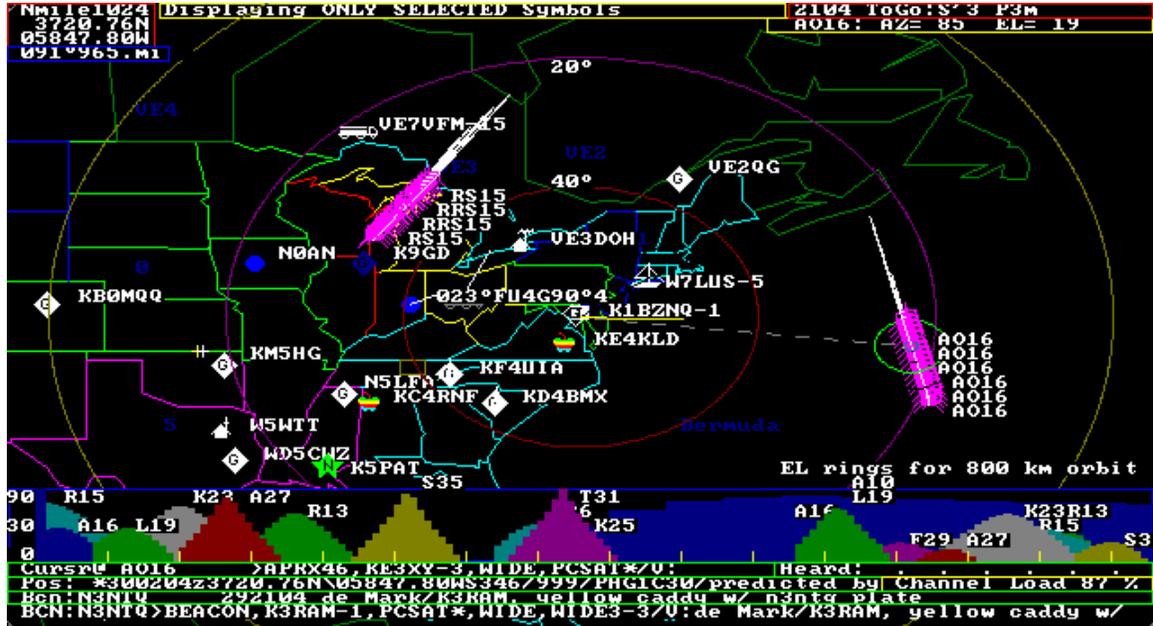
All satellites are shown on the map as moving objects. Across the bottom of the screen the next 2.5 hours of satellite passes are shown in a graphic showing the maximum elevation of the pass.

DISTRIBUTING LIVE SAT TRACKING DATA TO MOBILES

Another version of the same APRSdos derivative is called APRSdata.exe and it has the unique feature that it can distribute via the terrestrial network sufficient pass information for display on the front panel of the Kenwood radios so that other travelers are aware of pass times long before they drive out into the wilderness. Not only does this put this special Satellite Pass Info directly on the mobiles' radio, it also posts the Satellites in view as objects to the local 144.39 network so that all mobiles can see the range and azimuth to the satellite as well as the up and downlink frequencies. Thus, our mobile satellite users can get the PASS info they need without lugging along a laptop.
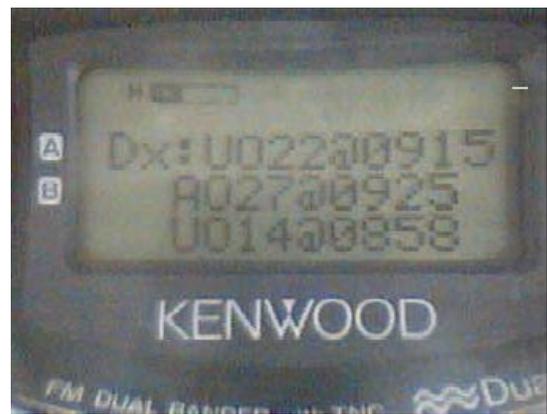

Photo 7. Screen shot of the TH-D7 showing the next 80 minute satellite schedule.

Bob Bruninga

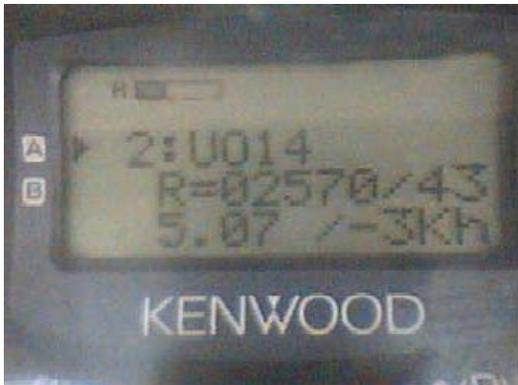15th Annual AIAA/USU
Conference on Small Satellites

Photo 8. Showing the range and downlink frequency of UO-14.

Photo 9. Showing the direction and distance to the Satellite.

The screen shots show what the TH-D7 HT will capture and display about the satellites while monitoring the terrestrial network if an APRSdata.EXE station is in range. First is the DX-SPOT list showing that there are three satellites UO22, AO27 and UO14 coming up in the next 80 minutes and when.

The next two screens show up when the satellite is in view. They show the Range, Azimuth Frequency, Doppler and distance to the satellite. Just perfect for aiming your handheld antenna. For more details on this resource for non-PC distribution of satellite info, see the WEB site:

http://web.usna.navy.mil/~bruninga/satinfo.html

The power of this on-line, real-time delivery of current satellite pass data to mobiles and handheld users without the need for a laptop is in itself a brand new opportunity for the Amateur Satellite Service. Already it has been expanded to hundreds of other data screens that can be pushed to these radio displays. We call them Tiny Web Pages [10]. Although this application is beyond the scope of this paper, the ability to deliver these Tiny Web Pages to any HT/Mobile anywhere on the planet with the combined resources of the existing APRS infrastructure and the ASTARS Amateur Satellites.

CONCLUSION

The time is ripe for extending Amateur Satellite digital communications services to mobile and handheld users. Since packet was first introduced on the Space Shuttle mission STS-35, there have been numerous experiments to test and validate the capability for using UI packet digipeating for real-time digital communications between users. This combined with the recent maturity of the Internet as a global resource for exchanging data worldwide suggests that there is a unique opportunity to join the advantages of the Internet and Amateur Satellites as a means of tying together SatGates throughout the world where the infrastructure exists to extend worldwide amateur communications to mobiles in areas where it doesn't exist. And, rather than starting such a global system from scratch, the APRS protocol and worldwide internet infrastructure provides a means of packaging and delivering and displaying this type of real time traffic to users both on the satellite downlink and worldwide via the Internet.

The introduction of the Kenwood and Alinco integrated TNC/Radio combinations and the Kantronics

TNC's give us off-the-shelf solutions for providing mobile and handheld Satellite Communications Terminals to all users. By encouraging UI digipeating as auxiliary payloads on most small satellites the Amateur Satellite Service can bring all of these pieces together into the most powerful and far reaching Amateur Satellite project to date.

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