Communications On The Move Design Considerations: A Systems Perspective

July 2008

Advancing a Connected World

iDIRECT

This paper will discuss elements and considerations of providing satellite communications on a moving platform from a systems perspective. Communications On The Move (COTM) has gained a great deal of attention recently – the need for broadband connectivity on a moving vehicle has increased dramatically in the past few years for both commercial and military applications. Whether the platform is marine, terrestrial or airborne, there are a number of physical, operational and security considerations that must be taken into account. This paper will focus on Internet Protocol (IP) over satellite, since IP communications has become the dominant protocol for newly deployed voice and video applications. Since communications links of individual terminals in a network will vary based on applications, antenna size and traffic profile, this white paper will also focus on a COTM network capable of simultaneously supporting star, mesh and SCPC topologies.

In addition, due to the nature of COTM systems, global connectivity must be addressed. A global COTM network has much greater degree of complexity than a regional network since it requires beam switchover and IP routing re-convergence as a vehicle moves from one satellite beam to another. This paper will present the iDirect approach to COTM systems design including antenna size and link budget, spectral density, the Doppler Effect, beam and teleport switchover, and security.

Physics of Small Antennas: Link Budgets

With few exceptions a moving vehicle will require a small antenna. To accommodate market demand antenna manufacturers have been working diligently to develop either stabilized parabolic antennas or phased array antennas with very, very small apertures and profiles. These remarkably small and agile antennas, while a triumph of technology, are still limited by fundamental laws of physics and antenna gain. The size of the antennas limits the total radiative energy it can collect, as well as the ability to focus energy on the Block Up Converter (BUC) and Low Noise Block (LNB). As a result, a link budget will dictate increased transmission powers and satellite bandwidth usage. With the recent advancements in technology of DVB-S2 and Adaptive Coding and Modulation (ACM), maximum throughput can be achieved by utilizing the most efficient coding and modulation scheme dependent upon the location within the satellite beam, antenna size, and sky conditions.

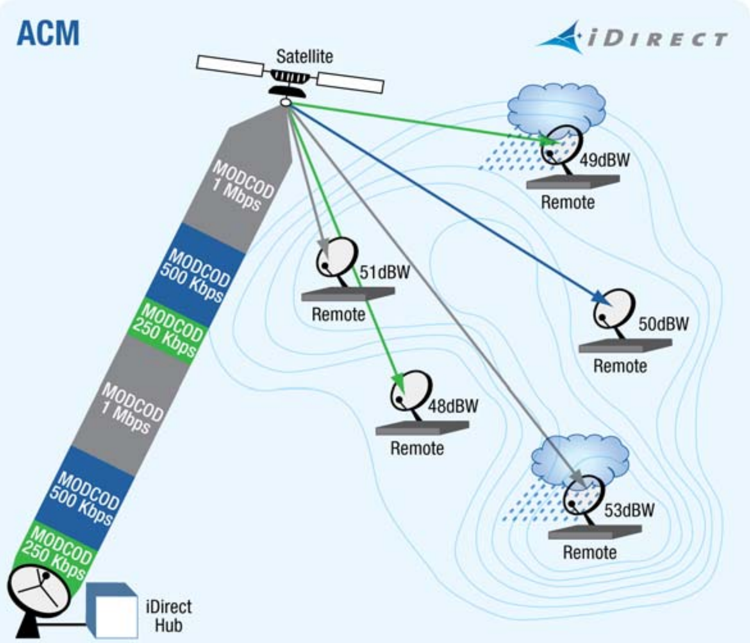
DVB-S2

Implementation of DVB-S2 satellite transmission protocols as an out-route carrier can offset some of the link budget issues encountered by greatly mitigating the power and spectral density problems encountered. DVB-S2, a second generation specification based on Time Division Multiplexing (TDM) technology, incorporates two very powerful features both of which help in utilizing ultra small antennas. The first DVB-S2 feature which is useful in COTM deployments is Low Density Parity Check (LDPC) forward error correction. DVB-S2 LDPC is a forward error correction coding which provides a communications link that is closer to the theoretical Shannon limit than older Forward Error Correction (FEC) algorithms such as Turbo Product Codes (TPC). Typically LDPC codes perform 0.7 to 1.2 dB better than TPC.

Adaptive Coding and Modulation (ACM)

The second and perhaps more powerful feature of DVB-S2 for COTM applications is Adaptive Coding and Modulation (ACM). ACM automatically adjusts the out-bound channel coding (FEC rate) and modulation (BPSK, QPSK, etc.) adapting in real time to changing link conditions including rain fade, antenna pointing, interference, reduced transponder power, and the edge of footprints. Typically, the benefits of ACM are associated with atmospheric attenuation. However, in COTM applications the true benefit of ACM comes into play as a vehicle moves toward the edge of a beam.

Extensive testing and link budget analysis of various vehicle mounted COTM antennas by iDirect show most out-bound links can be closed without exceeding spectral density limitations when DVB-S2 with LDPC and ACM is employed.



ACM enables each remote to achieve maximum data throughput by utilizing the most efficient coding and modulation scheme dependant upon the location within the satellite contour, antenna size, and clear sky conditions versus rain fade.

Spectral Density

A fundamental characteristic of an antenna includes the ability to focus a beam and its side lobe characteristics. In general, the larger the antenna the tighter the beam can focus on the satellite. Conversely, sub-one meter antennas have a tendency to spread RF energy over a very wide area. Since satellite spectrum is so limited, adjacent satellites will often utilize the same frequency and polarization, relying on the physical 2 degree separation of satellites to minimize interference.

The amount of interference allowed from adjacent satellite communications is specified by the International Telecommunications Union, the FCC, as well as coordinated agreements between the satellite operators. The interference is characterized in units of dBW/Hz and is known as spectral density. Based on international or coordinated agreements, a remote satellite terminal may not unintentionally transmit energy to an adjacent satellite greater than a given Φ dBW/Hz. A COTM remote utilizing sub-one meter antennas and transmitting at high power to close a given broadband link could, in many cases, exceed the coordinated agreement for adjacent satellite interference. The satellite engineer’s challenge then becomes how to provide ubiquitous broadband connectivity on a moving platform without causing or being effected by, excess adjacent satellite interference.

Fortunately, there is a widely accepted, time proven technology known as Spread Spectrum which can solve the adjacent satellite interference problem.

Spread Spectrum

Quite simply, Spread Spectrum takes an RF signal of a given bandwidth and spectral density and multiplies the occupied bandwidth by the spreading factor while dividing the power by the same spreading factor. To be more specific, Spread Spectrum takes an RF signal of a given bandwidth Ψ MHz and spectral density of Φ dBW/Hz and spreads it by a factor Z, resulting in an RF signal (Z x Ψ) MHz and spectral density of (Φ/Z) dBW/Hz. Given a large enough spreading factor a satellite engineer can overcome virtually any adjacent satellite interference problem. The cost is in the increased amount of satellite bandwidth required to support given applications.

CDMA Spread Spectrum

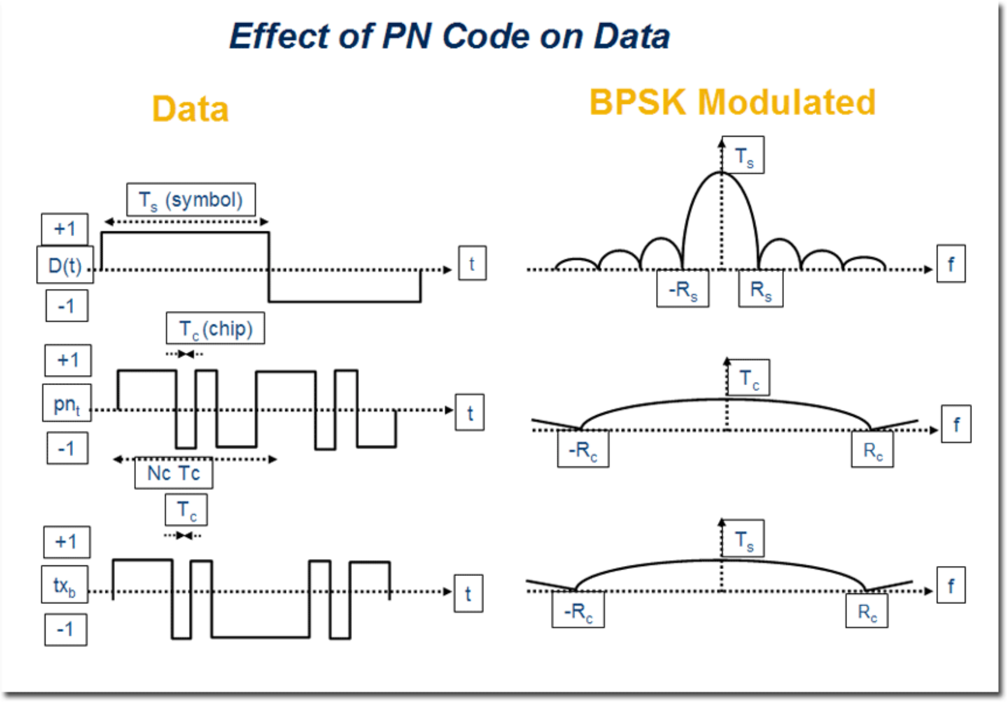
There are a number of Spread Spectrum techniques available for consideration. The most prevalent Spread Spectrum technique is Code Division Multiple Access (CDMA). CDMA Spread Spectrum is used in many of today's cellular networks. In CDMA the bandwidth of a given phone conversation is spread by a large factor and appended with a unique code. The demodulators used in a handset can identify its unique code from the rest of the simultaneous calls and demodulate its own unique signal. Since CDMA Spread Spectrum is used in so many cellular systems throughout the world one could leverage the economies of scale and build very cost effective Spread Spectrum demodulators for the satellite market.

Unfortunately, CDMA is unsuitable for satellite communications and ultimately will not solve the adjacent satellite interference, spectral density problem. The reason CDMA Spread Spectrum will not solve the adjacent satellite interference problem is quite straight forward. Since each remote in the network is transmitting a certain spectral density Φ dBM/Hz defined by the transmitted power and spread factor, the total spectral density reaching the adjacent satellites will be (N x Φ) dBM/Hz where N = number of remotes in the network. Clearly, the coordinated adjacent satellite interference spectral density could quickly be exceeded as remote terminals acquire into the network. This problem could be overcome by spreading the bandwidth further or limiting the number of remotes in the network, but neither of these is a cost effective solution.

Direct Sequence Spread Spectrum

The more practical approach to Spread Spectrum, and the approach adopted by iDirect for a COTM network, is to apply Direct Sequence Spread Spectrum in a TDMA architecture. In Direct Sequence Spread Spectrum (DSSS) the stream of information to be transmitted is divided into small pieces, each of which is allocated to a frequency channel across the spectrum. A pseudo random number is applied to data entering a carrier modulator. The modulator therefore sees a much larger bit rate, which corresponds to the chip rate of the pseudo random code number sequence. The spectrum is therefore spread by the chip factor. By utilizing DSSS in a TDMA architecture only one remote terminal will be transmitting at a time, thereby lowering the required spread factor and yielding a much more resource efficient system. The iDirect spreading factor is adjustable between 2 and 16 times. This will enable a satellite engineer to use just the minimum amount of bandwidth to support his unique COTM network.

Input:
Binary date D(t) with symbol rate R(s) = 1/T(s)
Pseudo-noise code pn(t) with chip rate R(c) = 1/T(c)



The Doppler Effect

The Doppler Effect has been a consideration of satellite modem manufacturers for some time. The Doppler Effect is the change in frequency of a wave as perceived by a receiving station as either the transmitter or the receiver moves. Historically, the Doppler Effect in satellite transmission has been a secondary consideration arising due to the motion of the satellite in its station keeping box. With high speed COTM vehicles such as aircraft the Doppler Effect has a great impact on the effectiveness of demodulators. The amount of Doppler Effect observed from a moving vehicle is dependent on the geometry of motion. For example, whether the aircraft is moving toward or away from the satellite +/-, as well as the angle θ, the velocity, and the acceleration of the vehicle. The formulas here quantify frequency shift based on the pertinent variables.

UNIFORM VELOCITY

$$\text{Time Drift} = \frac{\pm v{*}\cos(\theta\ E1) * 10^{9}}{c}\ \text{(ns/s)}$$

$$\text{Frequency Shift} = \frac{\pm V{*}\text{fcarrier}{*}\cos(\theta\ E1)}{c}\ \text{(Hz)}$$

$$\text{Frequency Drift} = 0$$

UNIFORM ACCELERATION

$$\text{Time Drift} = \frac{\pm (v{*}at) * \cos(\theta\ E1) * 10^{9}}{C}\ \text{(ns/s)}$$

$$\text{Frequency Shift} = \frac{a{*}t{*}\text{fcarrier} * \cos(\theta\ E1)}{c}\ \text{(Hz)}$$

$$\text{Frequency Drift} = \frac{a{*}\text{fcarrier} * \cos(\theta\ E1)}{c}\ \text{(Hz/s)}$$

Since terrestrial and maritime vehicles travel relatively slowly, the Doppler Effect does not come into play; however it is a major factor on airborne platforms. For comparative purposes, at Ku band an aircraft travelling at 1,188 Km/h and experiencing 1.7 G acceleration with a zero degree look angle will have an uplink frequency shift of 15,950 Hz. Such large frequency shifts must be compensated for. For the in-bound, in the iDirect system such frequency shifts have been accommodated through advances in demodulator code, primarily by adopting a multiple correlator structure.

Beam and Teleport Switchover

Fast moving and long distance COTM terminals such as aircraft and ships will need to be handed from one beam to another and from one teleport to another as global coverage is only achieved using multiple C- or Ku-Band beams. Mobility poses a number of challenges for IP networks and network management systems. Basic IP network design assumes core network devices like routers and switches will remain at a fixed location even if host devices come in and out of the network. Dynamic routing protocols like OSPF, RIP v2, ISIS, BGP and others are designed to accommodate subnets being added to and deleted from a network and for interconnecting links to come in and out based on outages. The new requirements for mobility in the satellite market allow for IP routers built into remote terminals to move from beam to beam, from teleport to teleport and from continent to continent. COTM mobility requires a new approach to the design and management of satellite networks.

Global Network Management

To address this challenge iDirect has developed a Global NMS, which is able to track, monitor, and maintain contact with mobile remotes over multiple networks on multiple hubs anywhere in the world. This enables a single COTM remote to have multiple instances in teleports around the globe. The iDirect Global NMS is flexible enough to allow IP addresses to remain fixed while allowing for differences in configuration across different beams including varying out-route and in-route sizes as well as different QoS profiles.

Automatic Beam Switching

One of the most challenging aspects of COTM remotes involves switching from one beam to another. Beam switchover requires both the ability of the remote to determine when and to which beam to switch as well as integration with the COTM antenna. To determine the optimal point at which to switch beams and the most appropriate beam to switch to, iDirect has developed an Equivalent Isotropically Radiated Power (EIRP) map server. The iDirect EIRP map server holds the familiar contoured EIRP satellite maps. The remote, having access to latitude and longitude information from a GPS, is coordinated with the EIRP map server and determines the appropriate place and time to switch beams. To facilitate beam switchover iDirect has integrated with a number of stabilized antenna manufacturers including SeaTel, Orbital and others.

Security

COTM and itinerant terminals pose new challenges from a security perspective as well. The need for advanced encryption over the satellite link is obvious. As a remote moves from location to location and beam to beam, one never knows who may be listening to the link. Satellite service providers will need to offer strong encryption such as 256-bit keyed AES and for government users FIPS 140-2 certified encryption will be required.

TRANSEC

For very high security requirements iDirect has developed Transmission Security (TRANSEC) for TDMA-based COTM systems. TRANSEC has a number of components including the ability to obfuscate any traffic volume or remote terminal activity information which may allow an adversary to infer useful information based on activity levels.

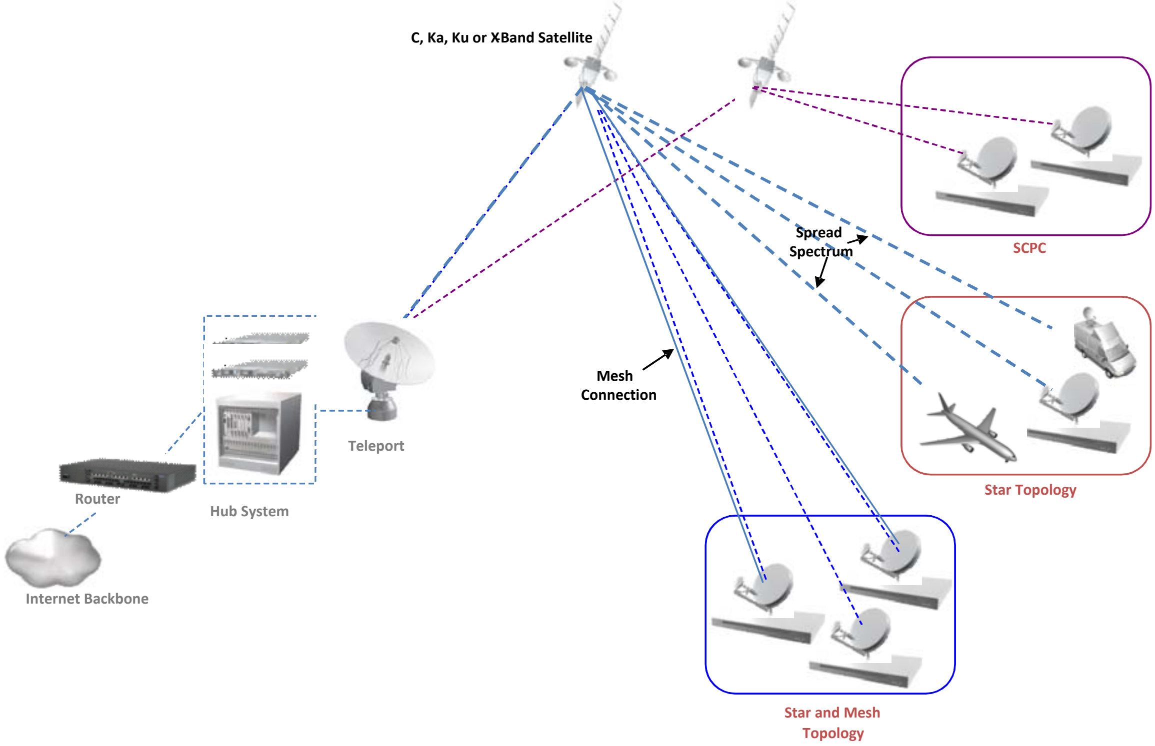
It is doubtful any commercial applications will require the level of security TRANSEC provides. There is one aspect of TRANSEC, however, that may prove beneficial in a commercial network. The more mobile and dynamic a network is, the more vulnerable it becomes to rogue remote terminals gaining access to the network. Most satellite NMS systems authenticate a remote terminal by verifying a physical hardware address in the remote terminal, similar to a MAC address in Ethernet. It is theoretically possible for an adversary to change the hardware address of a remote. Once a remote’s hardware address has been changed it could be acquired into a restricted network.

There is a component of TRANSEC for TDMA VSAT systems known as X.509 certificates which could be employed in both commercial and military networks that would stop such intrusions. X.509 certificates are a standard, RFC 2459, and are simply a digital certificate issued by Certificate Authority (CA). The X.509 certificate uses the Public Key Infrastructure and leverages RSA public key encryption. In this way, a remote can be authenticated to a teleport and a teleport to a remote. By employing X.509 certificates a network operator can be assured all remotes acquiring into the network are authorized and that remotes in the field will not acquire into an adversary's network. The iDirect NMS has the capability to accept third party certificates or to generate its own.

Future Network Architectures

In the future, deployed VSAT networks will consist of fixed and mobile remotes. Some applications will require mesh connectivity, some terminals will be mobile and some links will require high bandwidth SCPC links. Varying terminal characteristics will necessitate different modulation techniques and in-route link types. The ideal VSAT platform will simultaneously provide all the above. Furthermore, the system will ideally be a software defined radio. This will enable the operator to simply upgrade software as new technologies are developed and deployed.

The iDirect iNFINITI and Evolution platforms and Global NMS satisfy all these requirements. The 5IF hub chassis can simultaneously support multiple star, mesh, and SCPC links operating over as many as five RF chains. iDirect iNFINITI remotes can operate at 8PSK, QPSK, BPSK or spread spectrum with a wide variety of TPC Forward Error Correction rates. The Evolution DVB-S2 remotes can operate at 8PSK, QPSK, and 16APSK with LDPC Forward Error Correction capabilities. The iDirect award-winning Global NMS allows a remote to be defined in multiple networks simultaneously around the world. A network operator can protect the entire network and user data by employing TRANSEC or simply encrypting user data.



The advent of COTM technology has opened new opportunities and new markets for satellite service providers and hardware manufacturers. These new COTM opportunities present a number of new physics, operations and security challenges. A holistic approach to COTM network design is needed. A network will underperform if it is designed to provide high data rates operational on an 18 inch dish but it cannot switch beams when necessary and take an entire transponder to support a small number of terminals. The tight integration of the remote terminal, NMS and antenna is critical for the entire implementation and support of COTM networks.