The challenges of providing appropriate GSM service to the commercial maritime market

Communications at Sea: The Problems

Crew members of commercial ships encounter numerous difficulties in conducting the most basic communication, such as phoning and text messaging with their family and communities around the world.

- Telephone calls over satellite phones are prohibitively expensive for frequent personal use.
- Satellite calls require allocating/limiting time per crew member.
- Getting incoming calls quickly and easily to the correct person is challenging at best, since one phone number is shared.
- Alternatives such as Voice over IP (VoIP) phones, analog telephone adapters, or soft phones such as Skype™ consume far too much bandwidth to be economically viable.
- The ubiquitous GSM handset will not function in international waters, outside the range of land-based mobile networks.
- Current satellite-based solutions that provide GSM coverage on cruise ships, typically with 1,000+ passengers, do not economically scale down to support the crew complement of commercial ships, for a variety of technical reasons described below.

Solution Highlights

Affordable mobile phone service for the commercial maritime industry would greatly benefit both fleet operators and crews.

The recent introduction of "Always On" mobile satellite services allows the installation of GSM base stations on board.

However, the very high costs of bandwidth plus the use of firewalls and NATs means traditional "mobile network" solutions to provide GSM services are not economical for commercial ships. Solutions available for cruise ships do not appropriately scale down.

Novel GSM Base stations with a highly optimized "VoIP Architecture" can provide multiple benefits over alternative solutions, including regular, pre-paid mobile phone service for crew members, simple installation and service provisioning, and overall lower costs.

A technical solution to address the problems identified above needs to efficiently combine (i) the recent availability of mobile "always on" satellite Internet connections, (ii) standard GSM service that crews are familiar with and will pay for, and (iii) GSM base stations that are truly optimized for commercial ships, not scaled down versions of cruise ship technology.

Other maritime GSM solutions have historically attempted a "land-line mobile network" approach that has limited the adoption to date. Although the benefits of offering regular mobile phone service on ships is widely appreciated, the up-front cost and high bandwidth utilization means the "land-line mobile network" approach is simply uneconomical (for reasons discussed in detail below). By applying *advanced* VoIP techniques to connect GSM base station servers over the mobile satellite connections, a technical, economical, and easy to use solution to the problems outlined above becomes clear.

Mobile, "Always On" Satellite Internet Connections

The commercial maritime industry has traditionally been a global leader in the deployment of satellite-based voice and data services. Over the past few years, a new class of "always on", IP-based satellite services such as FleetBroadband, mini-VSAT Broadband℠, and SeaCast™ have emerged.

Commercially available "Always On" connections for ships allow the routing of IP packets and support important Internet services such as web browsing and email. The connections may include multiple levels of firewalls and network address translation (NATs), both on-board and with the satellite ground station. These firewalls and NATs both (i) allow multiple devices on the ship to communicate with other hosts on the Internet by sharing a publicly routable IP address and (ii) prevent unsolicited packets from being received via the satellite (and thus incurring the costs of the bandwidth).

Although "always on" represents a significant improvement over the previous generation of satellite data services – which are analogous to "dial-up" Internet connections – the bandwidth cost remains expensive compared to traditional landline Internet connections. Due to the high cost of satellite deployment and the inability to readily ease bandwidth constraints, "fixed-station" satellite services are orders of magnitude more expensive than land-line broadband solutions with similar capacity. Mobile satellite services generally remain at least an order of magnitude even more expensive than traditional "fixed-station" satellite data services primarily due to the significantly lower signal-to-noise ratios – and resulting lower overall channel bandwidth – which results from movement of the ship. Gimbals can keep an antenna approximately pointed at an appropriate satellite as the ship moves both locally and globally, but the beam alignment for a rotating/moving ship will be less precise than fixed-station satellite connections. Consequently, the ***cost of mobile satellite IP connections is approximately five orders of magnitude more expensive than a land-line broadband connection***[1]. Therefore, standard VoIP solutions designed to utilize low-cost broadband available on land remain expensive and inappropriate for networks with mobile-satellite connections.

Challenges for VoIP Solutions over Mobile Satellite Links

Worldwide, the rapid growth of packet-switched networking (*i.e.*, the Internet) is gradually replacing traditional circuit-switched networking of the Public Switched Telephone Network (PSTN). Placing phone calls via the Internet is referred to as VoIP, which is also widely recognized as the future direction of voice communications.[2] Applying VoIP techniques over the "Always On" IP links may initially appear to be a viable alternative for enabling GSM service on commercial ships, but many separate problems must be addressed in order to provide reliable, high-quality, and cost-effective service.

Many commercial VoIP services are focused upon traditional land-line broadband and wireless connections. A commonly used codec for compressed voice is the G.729 codec transmitting with 20 ms frames, or 50 packets per second. Although the codec may be only 8 kilobits per second (kbps), the overhead in a standard configuration is an additional 16 kbps, for a total of 24 kbps in a single direction. The 16 kbps comprises 20 bytes of IP headers, 8 bytes of UDP headers, and 12 bytes of RTP headers.[3]

[1] List price per **GB** with Amazon Web Services is $0.10. List price for basic mobile satellite IP is ~$10 per **MB**

[2] For example, phone calls placed on the 4th generation of mobile networks (4G) are natively VoIP.

[3] Voice Over IP - Per Call Bandwidth Consumption – Cisco Document 7934

Header compression is generally not viable since the intermediate NATs and Firewalls between the sender and the Internet must have full headers in order to properly route the packets.

Clearly, 24 kbps in each direction (or a total of 48 kbps) is far beyond the economical range of mobile satellite systems where the total bandwidth must be well below ~16 kbps in order to become economically viable. Simply implementing Voice Activity Detection (VAD) and not transmitting packets during silence is insufficient since that cuts the total example bandwidth for the standard G.729 codec from 48 kbps only down to 24 kbps. Selecting more highly compressed codecs does not solve the issue of high bandwidth utilization for packet overhead, which, again, is typically 16 kbps for 50 packets per second. Additional concerns for the optimal selection of a VoIP codec include the robustness of the codec against (i) bit errors and the probability of bit errors being propagated into the datagram and (ii) packet loss, such that if a single frame is entirely lost the impact on subsequent frames is minimized (*i.e.*, inter-frame dependencies should be minimized).[4]

As also noted previously, firewalls and/or NATs are widely deployed with mobile satellite broadband connections. While the firewalls increase security, they also create significant challenges to VoIP service providers who wish to economically maintain "pin-holes" in the firewall to signal incoming calls or messages. For example, a standard VoIP phone, analog telephone adapter, or softphone such as Vonage™ will consume generally 25 – 50 Megabytes (MB) per month of bandwidth by simply remaining connected to the Internet, before a single telephone call is placed or received. Such bandwidth consumption, which is not a problem for regular broadband connections such as DSL and cable, is clearly uneconomical for mobile satellite applications, where each MB of data can cost upwards of $10 – or $500/month just to operate the service.

Mobile satellite IP connections provide additional challenges for VoIP applications due to jitter and delay that are typically significantly higher than other broadband services. Jitter buffers at both ends must be properly tuned to compensate for the higher jitter and flexibly adjust to a wide dynamic range. Improper settings on jitter buffers can result in degraded audio (via apparent packet loss) or excessive delay (3-5 seconds in each direction).

GSM Service for Commercial Ships – Key Technical Features

Deploying a GSM base station server onto a ship to leverage the "Always On" Internet connection can provide several valuable features including: compatibility with the most handsets, ease of installation of the base station, and the ability to automatically set up pre-paid mobile service for each crew member.

GSM 2G and 3G services are the dominant international standard for mobile phone services globally, with more than 4 billion connections worldwide in 2009.[5] The vast majority of the crew complement carries handsets compatible with GSM 2G networks, which are common in both their home countries and destination ports globally. A solution offering voice and text messaging to the crew would ideally be fully compatible with these handsets. Note: 3G capable handsets are fully backwards compatible with 2G networks.

Additionally, the base station should operate on the most common frequency worldwide – the 900 MHz standard. Since the 900 MHz band is allocated in most countries to support GSM service, the selection of this spectrum will not interfere with other radio communications on-board. To further limit the

[4] A Scalable Coding Scheme Based on Interframe Dependency Limitation – IEEE ICASSP 2008

[5] Wireless Intelligence – GSMA Press Release February 11, 2009

potential for interference, selecting a single absolute radio frequency channel number (ARFCN) can limit base station RF emissions to a narrow frequency band of only 200 KHz, while also supporting up to 7 simultaneous phone calls.

GSM Base Stations for Commercial Ships

Traditional GSM base stations, including picocells, commonly connect with a mobile operator's network using interfaces such as A-bis, Iu-b, UMA, or similar mobile network standards. These interfaces consume considerable bandwidth and have timing constraints which make the solutions either expensive or inoperable with traditional mobile satellite connections. These interfaces were fundamentally designed for circuit-switched networks (*e.g.*, T1s, E1s, E3s, ATM, etc.) instead of a packet-switched network (the Internet). Even by applying compression techniques on the interface data, the bandwidth consumed over the satellite link is not sufficiently reduced. For example, transmitting frequent messages during idle states utilizes IP header bandwidth in order to transmit the compressed interface data. Further, these traditional mobile network interfaces for connecting base stations (A-bis, Iu-b, UMA, etc.) were not designed to interoperate with NATs and firewalls; such support was later "bolted on" with resulting inefficiencies, including increased bandwidth usage.

One alternative approach to back-hauling a mobile network interface over the satellite link is to include most of the essential functionality of a mobile operator's network onboard the ship, which is a common approach for providing GSM services for cruise ships. This approach addresses the base station back-haul problem noted above, but introduces a new class of problems related to interconnecting the on-board mobile switching center (MSC) to other network elements via SS7 MAP (mobile application part).

Similar to the issues for A-bis and Iu-b standards, SS7 MAP was not designed for an IP connection through a NAT/Firewall with expensive bandwidth. For example, the network overhead messages to maintain connectivity between an on-board MSC and land-based MSCs are typically significant, as demonstrated by the SS7 MAP specifications requiring at least a 56 kpbs dedicated link.[6]. The SS7 MAP network overhead messages and associated bandwidth, frequently implemented with SIGTRAN, can readily be allocated across a mobile network deployed on a cruise ship with 1,000 or more potential subscribers. But when scaling down these cruise-ship-focused solutions to the commercial vessel, it becomes uneconomical to justify an SS7 MAP link (equipment and bandwidth) for a single AFRCN base station with a limited number of potential subscribers (on the order of a few dozen per base station/SS7 MAP link).

Given the unique constraints and expense of mobile satellite connections, the optimal solution requires a radical departure from traditional "mobile network" solutions to provide regular GSM service to crew members. The solution requires an architecture that is fundamentally designed for both bandwidth constraints and the NAT/Firewall environment associated with computers operating in a commercial ship.

Additional Operational Issues to Consider

For ships with existing "always on" satellite IP connections, the installation of the base station should be as simple as 1) plugging in power, 2) connecting an Ethernet cable to the local area network, 3) placing a small antenna connected to the base station, and 4) switching on. The service provider should ensure all other configuration requirements are entirely handled "behind the scenes" so that crew members can install the base station server without requiring a technician to visit the ship. The base station

[6] Technical concerns in IP-based SS7 Signaling Network – Huawei 2007 – Experts Forum Issue 30

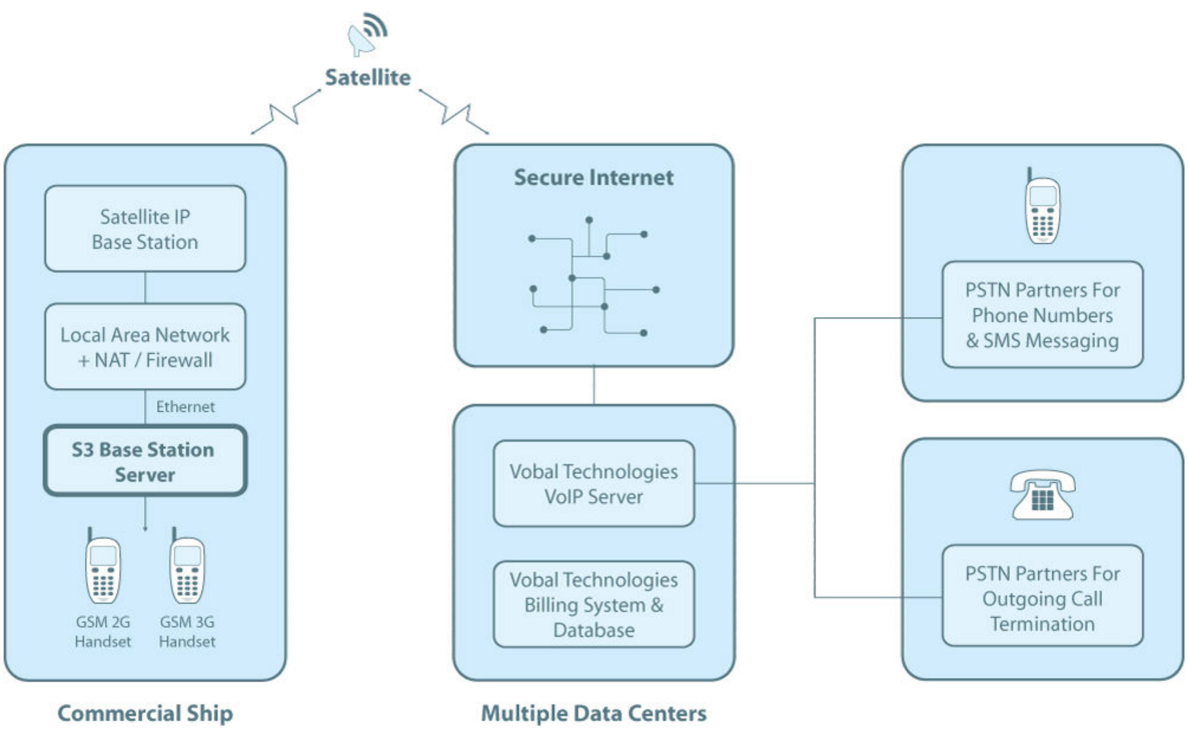
should be constructed of durable components to withstand rugged environmental conditions over many years, such as avoiding traditional disk drives and utilizing electrical components rated for at least 50,000 hours or longer of continuous operation.

The mobile service offered through the GSM base station should assign calling accounts to individual crew members as simply as possible. The service should be offered on a pre-paid basis to ensure that the usage of the satellite bandwidth is properly paid for by individual crew members (in the form of per-minute charges for phone calls). Payments for pre-paid should be supported through either "top-up cards" or web-based purchases.

The service should ideally be 100% compatible with the existing SIMs already installed on the crew's handsets, avoiding the cost and complexity of distributing SIMs to crew members. For example, a new crew member accessing the service for the first time could simply turn on his or her phone, enter a pre-paid code by sending an SMS (with instructions received via a "welcome" SMS), and be subsequently assigned a telephone number[7] and service. The phone number should follow the crew member from one ship to the next, so he may maintain the same number every time at sea.

The Solution – Vobal Technologies' VoIP Architecture for GSM Service

Given the significant challenges to providing economical and reliable mobile phone service to crew members, Vobal Technologies has developed an elegant solution that meets the requirements highlighted above. The architecture leverages more than a decade of success deploying VoIP solutions in operationally challenging markets, including the extensive use of satellite IP links. A high-level overview of the solution is outlined below:



[7] Note that using the existing phone number associated with crew member's SIM incurs additional costs due to roaming agreements with the SIM-issuing mobile operator providing the SIM. Further, many pre-paid services associated with the crew member's existing SIMs do not support international roaming. By associating a new telephone number to the crew member's existing SIM, the costs of providing mobile services can be reduced.

GSM 2G voice and data services are provided to the mobile phones from the Vobal S3 base station server. After connecting the base station server to power and plugging in the Ethernet connection, crew members are provisioned by simply having them turn on their phones and responding to a "welcome" SMS message. Note the simplicity of installation, which reflects years of experience for setup of VoIP services and IP phones.

A VoIP protocol connects the Vobal S3 base station server to Vobal Technologies' central servers; the VoIP protocol is highly optimized to compress the signalling and voice, while securely maintaining connection through the firewalls and NAT routers. The VoIP protocol is designed to keep the "idle state" bandwidth between the VoIP server and each Vobal S3 base station server to a minimum (reduced by an order of magnitude from the solutions listed above), while still enough to keep NATs from closing port bindings – allowing for incoming calls and SMS messages. The VoIP servers implement proven softswitch technology that has successfully supported tens of thousands of VoIP endpoints in production and thousands of simultaneous telephone calls.

The VoIP protocol includes advanced features such as media frame trunking both for the same call and across multiple calls, and minimizing the number of port bindings that remain open through the firewall/NAT. Media trunking combines multiple codec frames into the same IP packet, thereby reducing the number of packets required to transmit voice and the bandwidth associated with transmitting packet headers. In contrast to traditional VoIP applications such as SIP, Vobal Technologies' VoIP protocol does not use or require RTP headers on media packets, thereby saving on additional bandwidth.

The codec to carry compressed voice data across the satellite link is optimized both to provide high quality and to utilize low bandwidth. The total bandwidth, including both media and header bandwidth in both directions, is less than 10 kbps per telephone call. Note the bandwidth per call decreases with multiple simultaneous calls (*e.g.*, less than 8 kbps per call for four simultaneous phone calls). VAD is implemented to reduce bandwidth consumption, and jitter buffers on both the Vobal S3 base station server and the Vobal VoIP server are finely tuned to address the very wide range of jitter within mobile satellite IP connections.

In contrast to "traditional mobile network" base station technology, Vobal Technologies' VoIP architecture is also highly flexible and the company has full access to all source code for all major components. Customizations such as adding new features, utilizing different codecs (sacrificing call quality in favor of lower costs, for example), or interoperating with other equipment/networks can be more readily implemented than alternative GSM solutions. Many vendors of competitive products do not have full source code to all the key components of the base transceiver station, base station controller, and mobile switching center.

Security is maintained on multiple levels, including secure registration of each Vobal S3 base station server with the Vobal VoIP server, authentication and authorization of each call, and on the real-time billing system illustrated above. Since bandwidth utilization is a primary driver of costs for operating the service, bandwidth utilization for the Vobal S3 base station server is monitored both locally on the ship and remotely on the VoIP server. Note that (i) the mobile satellite network (such as FleetBroadband or SeaCast™) operates primarily at layers one and two of the traditional OSI stack (physical and data link layers), and (ii) IP packets are simply routed between the Vobal S3 base station server and Vobal Technologies' VoIP servers. As a result, no special coordination is required between a shipping company's mobile satellite IP vendor and Vobal Technologies.

The Vobal Technologies VoIP servers preserve the link between the Vobal S3 base station servers and the multiple PSTN carrier partners required to connect the calls. These carrier partners also route both inbound and outbound SMS messages to other mobile networks globally, and the multiple PSTN carriers provide redundancy to ensure high availability of calling services. Although not illustrated, both crew members and back-office staff within a shipping company can access Vobal Technologies' billing system through any standard web browser in order to view activity such as call logs, invoices and payments, etc.

Summary

In summary, Vobal Technologies' technical architecture leverages a proven VoIP approach coupled to a novel base station server. This architecture is a radical departure from traditional mobile network solutions with MSC's, SS7 MAP, A-bis backhaul, etc. Given the stringent technical and cost requirements to provide GSM service for the commercial maritime industry, Vobal Technologies' technical architecture provides a highly optimized solution. In addition, the business model offered to the shipping companies (not covered in this document; see www.Vobal.com for more detail) provides a unique opportunity for the ship owner/operators.

The balance of call quality and bandwidth usage (cost), the ease of setup, and the robustness of the technology of the solution has been specifically designed and optimized to meet the needs of the commercial maritime industry, both crew and ship owner/operators. As Vobal Technologies' website states:

Our vision is to enable the most appropriate cellular telephone service for the commercial maritime industry, measured by a combination of high voice quality, low bandwidth usage, high end-user value, and compelling business model for vessel operators.

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