LOOKING TOWARD THE FUTURE OF HF TECHNOLOGY

A White Paper by KNL Networks

8.11.2017

VERSION NUMBER

1.0

PUBLISH DATE

8.11.2017

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AN INTRODUCTION FROM OUR CHIEF TECHNOLOGY INNOVATION OFFICER

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What does the shipping industry and military have in common? One answer is a deep history with HF (High Frequency) communications.

HF is an old radio technology, but today in the maritime industry, these systems continue to be used thanks to IMO regulations which makes it mandatory to have a HF transceiver onboard. These GMDSS HF radios are, by modern standards, merely just analog HF radios with some very basic add-on digital capabilities. These are not modern forms of communication; they still use technology from the 60's and in practice are only used in emergency situations.

Militaries, on the other hand, still rely on the HF technology in special cases for reasons like communication security, communication redundancy, and in sometimes, cost-efficiency.

These keywords are the same reasons why the maritime industry should have another look at the possibilities of the modern HF technology, especially given the massive performance improvements that are possible to attain with a mix of modern telecommunication achievements.

This white paper gives insight to the paradigm change that the HF technology has encountered and we'll share some of the giant leaps of telecommunication technologies. The paper highlights the possibilities and capabilities the HF frequency band possess.

HF BAND BASICS AND LEGACY USE

Starting with the evolution of HF technology.

By the International Telecommunication Union (ITU) definition, the frequencies between 3 MHz – 30 MHz are called the high frequencies.

Compared to the VHF (Very High Frequency) or UHF (Ultra High Frequency) bands, the characteristics of HF are unique. While the propagation range of VHF and UHF is limited to line-of-the-sight, i.e. some tens of kilometers, HF is able to propagate over thousands of kilometers. Thanks to this, it's possible to establish a signal between continent to continent, or from shore to the high seas.

There's a lot to HF. The frequency band still benefits from Line of Sight propagation, identical to VHF and UHF propagation modes, and through Ground Wave (GW) propogation that conducts via the surface of earth (sea or land) up to 500 NM, i.e., over much longer distances than LOS.

The extreme long-range HF links are established with the help of the Ionosphere, which reflects some of the HF frequencies back to the surface of earth. This is called the sky wave (SW) propagation where, in a sense, the Ionosphere acts as a natural satellite for the HF signals.

The Ionosphere also comes with its own set of challenges. The constantly changing state of the Ionosphere dictates the characteristics of the HF propagation range and level of signal distortion.

Luckily it's possible to estimate HF propogation through standard variables, defined by the Time of the day, Date, Year, the Space weather, and the user Coordinates (listed shorthand as TDYSC), implying that there are both predictable and unpredictable factors affecting the propagation.

Complicating matters, there are both short and long-term fluctuations on the HF channel. The short-term phenomena, like signal distortion, are always very unpredictable by the nature. Furthermore, it is necessary to understand that TDYSC based Ionosphere status is valid only per "channel" (transmission frequency), within about 500 kHz. Frequencies apart more than 500 kHz could experience totally different SW propagation even though they share the same TDYSC parameters.

As a result, to establish and maintain a long-range data link over HF channel between two HF radios, each radio would have to be able to correctly choose a channel that propagates at the exact moment based on the TDYSC information.

In practice, that would be just the first step. Next, it would have to be figured out if the channel is free from the other users or interference (it's possible to see a lot of interference on a HF channel). Then the chosen channel, together with the communication parameters, would have to be informed to the distant user (the receiver), so that the receiver is able to tune to the same channel with adequate set of communication parameters. On top of that, the preparedness to change the channel whenever required needs to be very high. This would be the case if some other user (with much higher transmission power) occupies the same channel, or the state of the Ionosphere changes in favor of some other channel.

Traditionally, the well-trained HF operators have tackled HF communications by using their experience (and the ears) in managing the tricks of HF channel selection. Thanks to this, only voice or telegraphy have been the realistic communication methods.

There have been serious attempts to overcome these difficulties. During the 80's and 90's, second generation (2G) ALE and third generation (3G) ALE protocols (Automatic Link Establishment) were developed and eventually standardized by militaries. ALEs alleviate some of the skills required from the radio operator by adding automatic methods to initiate and maintain a common HF channel between the transmitter and the receiver.

But the main drawbacks of both generations of ALEs are frequency agility and the channel selection speed. As a consequence, both ALE methods are simply too low performing to be able to secure the stability needed for Internet services over HF band.

LEGACY NO MORE.

What would we need to do to exploit the full potential of HF for global communication?

To rethink HF, first of all we need to forget all that old stuff, like 2nd Generation avnd 3rd Generation ALEs and more or less abandon all the legacy-contaminated standards. The hardware of most of the existing HF transceivers needs to be gotten rid of as well. For short: we need to start from scratch!

The key to master HF is to be adaptive , cognitive and very frequency agile, in the fastest way possible. To do so, one would need high performing radio hardware with powerful DSP (Digital Signal Processing), as well as efficient algorithms to exploit the DSP capabilities. On top of that, you would need tailored protocols to offer the robust bit pipe to the IP layerand the applications communicating over HF.

Cognitive system, in this context, refers to the abilities to observe the prevailing operational environment and adjust the system behavior accordingly.

Nowadays it's is possible to fulfil all of the above-mentioned requirements thanks to the evolution of ADC (Analog to Digital Converters) chips.

ADC is the one component that transforms the analog HF signal to digital form, i.e., from waves to bits. Due to state-of-the-art ADCs, the whole HF band is possible to digitalize straight from the antenna. Now with the signal in the digital domain, the variables related to signal processing, decoding, and finding the right HF radio to connect to is much easier than first using some analog signal processing stages in the radio.

This kind of radio is an ideal software radio. The widely used term software defined radio, in turn, has more hardware determined restrictions since there are some analog signal processing between the antenna and ADC. There's a small but significant difference when considering, for example, the flexibility of the radio regarding the communication parameters listed above.

The system radio frequency (RF) bandwidth and the consequent symbol rate on HF are usually much lower than most VHF/UHF systems. The system symbol rate has a direct effect on the computational complexity of the signal processing. Thanks to a couple magnitudes lower symbol rate on a digital HF receiver, much more efficient signal processing is possible to implement than, for example, used in many cellular technologies. The effective signal processing is in paramount when decoding the user data from the distorted SW signal.

With this kind of setup we would have a HF radio capable of receiving and digitalizing the whole HF band, have enough DSP power to do the many tricks needed to establish and maintain a robust link between two distant HF radios, and above all, could constitute a robust bit pipe that could bear Internet traffic over the HF channel.

So, why haven't anyone done this before?

BEYOND LEGACY WITH KNL.

Actually, it's already been done!

KNL Networks designed and implemented a HF radio like just described above. It takes in the whole HF band, finds an operational channel extremely fast, and is ready at all times to change the channel to avoid other users and interference. Most importantly of all, it supports data rates suitable to many Internet services. All this has been done with the help of cognitive principles that decide how the operational channel is chosen and maintained.

KNL's HF radio is not just the most advanced cognitive HF radio in the world, but should be seen as a user terminal on a multiradio platform. In addition to HF interface, KNL employs a cellular interface (currently 3G), GNSS (Global Navigation Satellite System, e.g., GPS) interface and Wi-Fi interface. In a simple setup, a user can connect a PC to the user terminal via two LAN-ports. Figure 1 presents the KNL user terminal.

In addition to cognitive software HF radio there's something else that needs to be considered. That's the capabilities to form networks.

Without the ability to form networks, users of cognitive software HF radios would be at the mercy of the prevailing Ionosphere conditions: sometimes there just would not be an available channel through the Ionosphere between, say, a ship and the shipping company headquarters . But by forming a network, the individual radio user has multiple options to build a connection and transmit data home.

Here, the situation turns upside down since the Ionosphere offers a channel to "somewhere" virtually all the time. To do so requires both the sophisticated networking methods and the abundance of "base stations" which to connect to. Put simply, the best way to fight back the misbehaving Ionosphere conditions is to, instead of just leaning into one possible link between user A and B, is to have multiple possibilities to make necessary connections.

NETWORKING WITH KNL's HF TECHNOLOGY

KNL's operational maritime network has two kinds of network members: ones with direct Internet access and ones without. The former ones with internet are typically ships at ports, ready areas, or just close to shore. The latter ones are the ships at the high seas. The direct Internet access is constituted over cellular networks that are nowadays available at most ports, many ready areas, and in close proximities of many coastlines. Cellular con-

» *The KNL user terminal. It's the main interface to the world's most advanced digital cognitive HF radio.*

nection is possible because the KNL user terminal has a built in cellular interface.

As a consequence, the ships having the direct Internet access have the potential to act as a gateway between the ships at the sea and Internet. These gateway user terminals can be seen as a base stations (BS) of the KNL's HF network. KNL's unique network technology, called MESH networking, enables this ship-as-a-base-station functionality. In practice it means, that as soon as a ship enters the cellular network coverage, the KNL user terminal changes its role from the mobile station (MS) to a base station. From the user perspective, all the same services are available regardless of the role (MS or BS) with an exception that in the BS role, full-blown Internet access via cellular interface is possible to offer to the user.

USE CASE EXAMPLES

Taking a look at KNL's communication network through an example

VESSEL NAME: M/S Ramones
PORT OF DEPARTURE: Miami
PORT OF DESTINATION: Rotterdam
COMMUNICATION OPERATORS:
KNL Networks

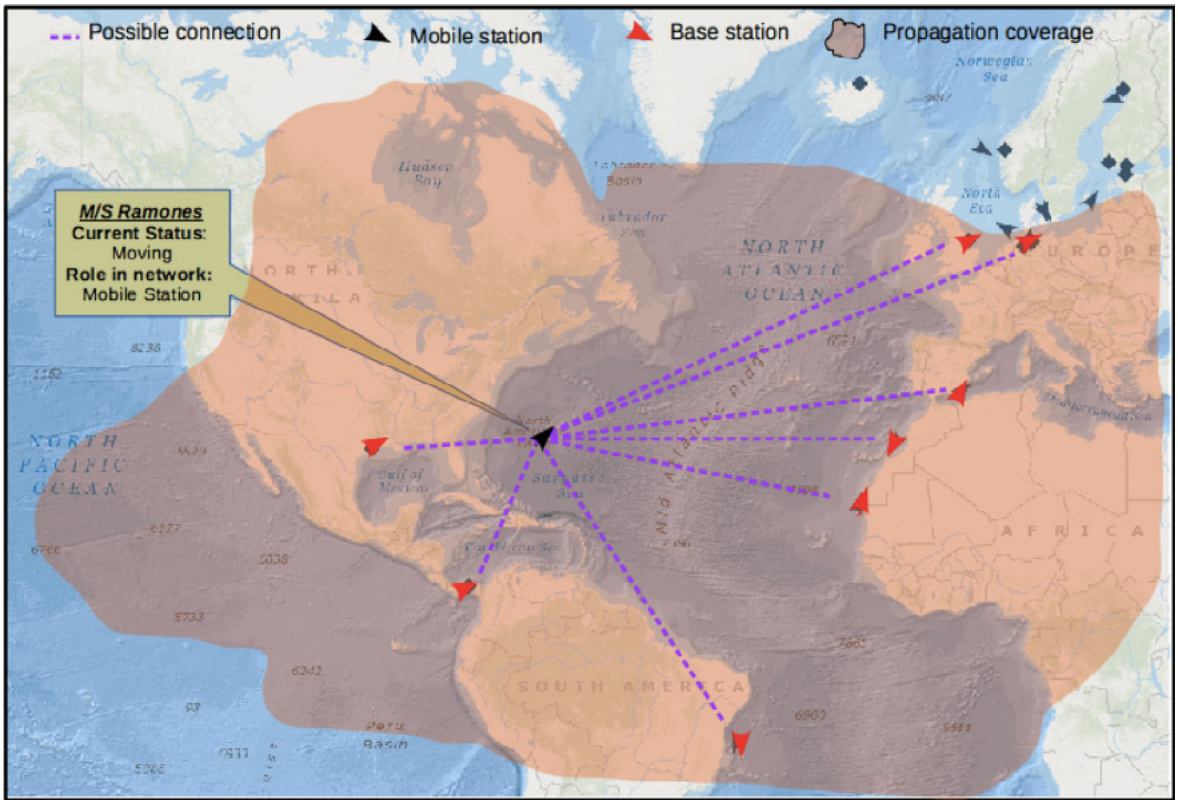
M/S Ramones starts the sailing towards Europe 9th of August 2017 at 16 pm (UTC).

During the first hour(s) M/S Ramones has direct Internet access through the KNL user terminal's cellular interface. After approximately 20 NM from the coastline, the cellular connection is lost and the KNL user terminal starts using the HF interface automatically. While in cellular network range, the user terminal at the bridge of M/S Ramones has acted as a base station for the other user terminals at the high seas, without any disturbance to the M/S Ramones.

During the following hours M/S Ramones takes connection via a HF channel to the closest KNL BSs located, e.g., at the port of departure. This is due to HF ground wave propagation which can reach up to 500 NM over the sea surface. Ground wave has many advantages over the sky wave, such as lower interference distance and more stable links. The obvious disadvantage is the limited propagation range. Therefore, the system uses GW whenever available.

Beyond the reach of GW, communication over the Ionosphere is the only option. This is exactly the domain where KNL's advanced HF technology shows its full potential. Since the departure, the user terminal has been aware of all the possible connections to the other BSs and MSs via Ionosphere it could have. Now it's time to exploit that knowledge. Depending on the aforementioned TDYSC status, the BS that M/S Ramones connects to could be on the other side of the ocean.

Figure 2 illustrates the MS-BS functionality. The signal coverage from the M/S Ramones (marked as a black arrow on map) is simulated by



» *Figure 2 illustrating the MS-BS Technology*

an industry standard HF propagation simulation tool. The simulation takes into account the TDSYC parameters (Aug. 9th, 2017 @location). Based on the real locations (taken from KNL's operational maritime network) of the ships there are eight potential base stations within the reach of M/S Ramones of which two are in North America, one in South America, two in Africa and three in Europe.

KNL system cognitive features take care that the most suitable BS is chosen per need. The optimizing requires taking into account both the user (application) needs and the network capacity. Therefore, the channels that both experience and cause minimal amount of interference are always preferred.

ADVANTAGES OF DIGITAL HF TECHNOLOGY

Going back to the beginning, there are three reasons why militaries have never abandoned the HF frequencies: security, redundancy and cost savings.

The exactly same reasons apply - or should apply - for the maritime industry as well. There are now new needs and threats for the maritime industry to consider in all those aforementioned domains.

As one example, the maritime industry is struggling more and more with communications security. Despite the many advantages of satellite systems, the satellite signal security is very hard to protect against even very simple jamming attacks. But on HF, on the other hand, the "vast" usable spectrum paired with cognitively provides protection against jamming attacks.

Due to possibilities of MESH networking there are no single point of failure in KNL maritime network: if one BS loses its connection to Internet the other BSs will serve both the needs of the network and that particular user terminal that just lost the Internet connection.

It is estimated that about 20 times more data is required by 2020. At the same time satellite capacity will double

Along with the emerging IoT (Internet of Things) on maritime, autonomous shipping, office at the sea, and the needs of many other Internet applications, the requirements of data will increase dramatically faster than the satellite capacity. In practice there have been more data demand than data offering in certain parts of the sea routes for long, which the users have been forced to accept. The actual news is that it will get worse if nothing is done. Satellite technology cannot solve this data demand by itself.

HYBRID NETWORKS

Using KNL's HF technology to your complete advantage

How do we see most shipping companies using HF communications? The answer is Hybrid Networks, which could be seen as a network of networks. This doesn't mean that HF, cellular and satellite technologies are assimilated on a network level, but rather than that the onboard systems utilize those distinct technologies in seamless manner, like changing from cellular to HF depending on a current need and availability.

On a conceptual level this is exactly what has happened in terrestrial systems. Inside the same handheld smartphone, there are embedded networking technologies ranging from 2G to 4G, together with Wi-Fi and Bluetooth link technologies. As a result of this hybrid networking, there is high capacity and good coverage in terrestrial mobile networks.

CONCLUSIONS

Using the past to look ahead.

The history of wireless communications has started from the low end of the spectrum and rushed upwards in the frequencies as radio technology reached new development steps.

But with the advances in satellite and wired networks, high frequencies have been left behind years ago – and many industries never looked back since, until now. HF is in a way in optimal slot of the spectrum; it is just low enough not to penetrate Ionosphere (and therefore to propagate over long distances) and high enough to offer adequate bandwidths for digital communications.

The main trend in the communications industry is to use higher and higher frequencies, but KNL Networks has looked once more the HF and made it better than ever by introducing the technologies originally intended for VHF/UHF bands, including software radio, cognitive radio and MESH network technologies.

The Maritime industry is digitalizing at an accelerated schedule, and the bandwidth and access required by the industry needs a simple, secure, and reliable channel for global communications.

KNL's digital HF is more than ready to carry its portion of maritime user data. Depending on the use case, Digital HF can be seen as a stand-alone primary communication solution, back-up solution for cellular or satellite, or a hybrid solution somewhere in between.

Have any more questions? Get in contact and we're happy to share more.

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