Novel Maritime Communications Technologies

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ABSTRACT: Current maritime systems are to a large extent based on legacy analog VHF radios for ship-to-shore communications near port waters, and relatively low bandwidth digital satellite communications (SatCom) for long-range ship-to-ship and ship-to-shore communications. The cost of bandwidth for SatCom networks is expected to remain high due to the cost of launching satellites into orbit and also due to the stabilizers required for presently available on-board antennas. On the other hand, the legacy VHF system comprises low bandwidth radios incapable of supporting applications requiring high data rates. Unlike the terrestrial networks, advancement in maritime networks is severely lagging behind its land counterpart.
MARINTEK is the principle investigator of the MarCom project, a joint initiative between several national and international R&D institutions, Universities and Colleges, Public Authorities and Industry, funded by the industry itself and The Norwegian Research Council's MAROFF program, and aiming at developing a novel digital communication system platform to ensure the proliferation of innovative mobile network applications presently being widely implemented on land-based wireless systems.

1 INTRODUCTION

The infancy and youth of radio technology was primarily linked to maritime applications. Following his invention of the first operating radio transceiver in 1895, Guglielmo Marconi performed transmission experiments between two Italian warships outside the port of Spezia in 1897, where he managed to exchange radio messages at a distance of 22 km. Later he continued his experiments in England, where on Christmas Eve in 1898 he established radio telegraphy contact between the "East Goodwin" lightship and South Foreland Lighthouse in South East England. On 3rd March 1899 the steamship "R F Matthews" collided with this lightship, which alarmed the lighthouse ashore to obtain assistance. This was the first time ever a distress call was transmitted by radio from a ship at sea.

However, despite of the tremendous developments in radio technologies since that time, advancements in maritime networks are severely lagging behind its land counterpart, and novel solutions are needed to meet the imminent user requirements.

2 MARKET PULL VS. TECHNOLOGY PUSH

2.1 *The 'Northern Challenges'*

The overall backdrop of the maritime communications market pull is demonstrated by Figure 1, portraying the 'Northern Challenges', where Norway is chosen as an example with a geographical extension and economic dependability of an ocean area about 6 times the size of its mainland. The vast geographic distances and the economic importance of activities at sea in remote areas demand novel and innovative radio-based solutions. There are numerous unsolved research challenges regarding radio communications coverage throughout the vast region comprising e.g. the Norwegian Exclusive Economic Zone (EEZ) and the Arctic waters [1].

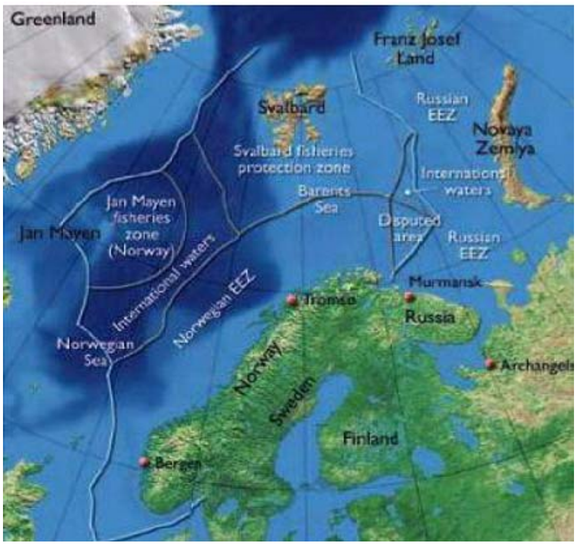


Figure 1 The 'Norwegian Challenges'; geography and economic activity at sea (Source: ACIA)

2.2 *MarCom scenarios and strategic initiatives*

The specific market pull issues and user requirements pertaining to the MarCom project are investigated through the following 9 scenarios/user cases:

1. Monitoring of (domestic) ferries
2. Pilotage & maintenance of fairways, lighthouses and navigation marks
3. Integrated operations (IO's)
4. Passenger information on trains and at roads
5. High-speed craft (HSC) operations
6. Vessel-to-Vessel Relay and Mesh networking
7. Mobile on-board LAN-solutions
8. The High North challenges
9. International shipping

Furthermore the issue of novel maritime communication technologies will be an important aspect of the emerging e-Navigation and e-Maritime concepts - e-Maritime being proposed by the EU Commission (DG TREN) as an extension to the already developing e-Navigation concept originating from IALA and IMO strategic initiatives.

Bearing in mind that the ocean waters cover about 70% of the earth surface, that over 90% of the world's goods is transported by a merchant fleet comprising around 46.000 ships, and that there are about 4.000 viable merchant ports worldwide - literally thousands of ships are out of sight from land or any other vessel all the time - and thus making the global needs for reliable maritime communications paramount.

2.3 *Compiled user requirements versus available communication capacity*

The compiled user requirements derived from the scenarios referenced in paragraph 2.1 above, along with similar supplementary data from the EU-projects 'Flagship' and 'EFFORTS', have identified the application groups given in Figure 2 ([2], [3]).

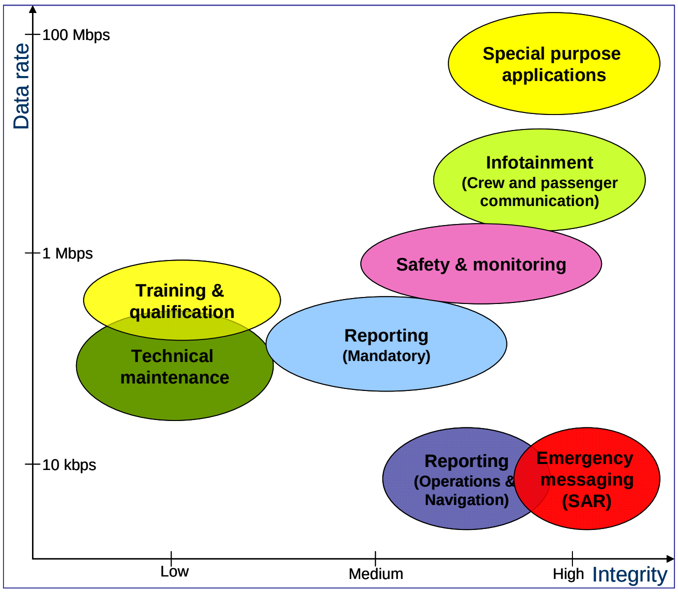


Figure 2 Speed vs. integrity diagram showing compiled user requirements in application groups [3].

It is obvious that but a few lower classes of these application groups may be supported by the presently available digital maritime communication means depicted in , and thus novel maritime communication technologies have to be introduced to the maritime market.

3 NEW MARITIME COMMUNICATIONS

3.1 *MarCom major objectives*

MarCom's major technological objectives are to:

- Extend the coverage and range at sea for both in-use and novel terrestrial wireless systems/ technologies
- Find appropriate SatCom solutions to complement/supplement the terrestrial ones, mainly beyond their coverage
- Obtain seamless and continuous handover and roaming within and between the systems

Table 1 Presently available digital maritime communications

System	Communication form	Data rate
NAVTEX	HF, MF	300 bps
DSC	VHF	1.2 kbps
GPS	Access via NMEA 0183	4.8 kbps
AIS	VHF	2 x 9.6 kbps
EPIRB	Short messages (Satellite)	100 bits/hour
SSAS	Short messages (Satellite)	100 bits/day
SafetyNET	NAVTEX over Inmarsat	100 messages /day
Some ships have digital data links via Satellite (Inmarsat, VSAT…)		

3.1.1 *Terrestrial systems*

The appropriate terrestrial systems being applicable for maritime use may be categorized as follows:

1. Cellular systems
2. Wireless Broadband Access (WBA)
3. Wireless Narrowband Access (WNA)

The roadmap for *Cellular systems* evolution towards an alleged introduction of 'Next Generation Mobile Network' (NGMN) is illustrated in Figure 3, the main features being steadily increased capacity and versatility [4]. A significant milestone on this path is the 4G-3GPP LTE ('Long Term Evolution') advancement, expected to offer peak data rates of about 300 Mbps downlink and 80 Mbps uplink.

Actual *WBA systems* comprise mainly Wi-Fi/WLAN and the emerging WiMAX technologies in accordance with the IEEE 802.11 and 802.16 standards, respectively.

For maritime users Wi-Fi is merely applicable for on-board purposes and close to shore (e.g. in harbors) due to its limited range.

However, WiMAX is considered a viable option for medium- to long-range broadband maritime communications, particularly if sub-GHz frequencies are applied - thus supposed to be capable of providing data rates > 20 Mbps at ranges up to 50-100 km [5].

Relevant *WNA systems* are Digital VHF (D-VHF) and (partially) AIS, but the latter is presently offering only 2 x 9.6 kbps, and thus of no interest to the bandwidth-demanding services in Figure 2.

As the 1st generation of D-VHF systems Telenor Maritime Radio (TMR) devised a technology providing a.o. a 'broadband' service of 133 kbps by utilizing 9 x 25 kHz VHF channels, with a range of

~130 km. TMR has deployed this system to cover all of the 2.400 km long Norwegian coastline, together with parts of the North Sea and the Norwegian Sea.

However, as a part of harmonizing the maritime D-VHF services a significantly more spectral-efficient solution has been introduced, indicating that the 2nd generation might increase the D-VHF's capacity by a factor of 3 -10 [6].

3.1.2 *Future trends – terrestrial wireless systems convergence or coexistence?*

WiMAX is designed to deliver multiple types and levels of service through a flexible IP network architecture, authentication and Quality-of-Service (QoS) mechanisms. WiMAX can be implemented as a flat 'pure IP' network or as a part of a multimode service environment through application servers, network gateways and IP Multimedia Subsystem (IMS).

LTE is now heading in a similar direction in creating Orthogonal Frequency Division Multiple Access (OFDMA) based networks, adaptive to various channels and signal conditions, and based on standards that comprise a framework allowing significant change and extension without breaking, an approach now looking obvious.

However, although several telecom advisers are predicting a convergence towards a NGMN concept as depicted in Figure 3, there are various reasons to believe that their coexistence will continue for several years to come.

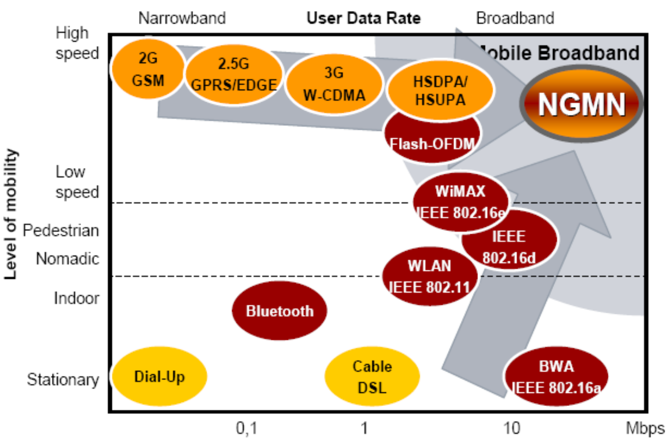
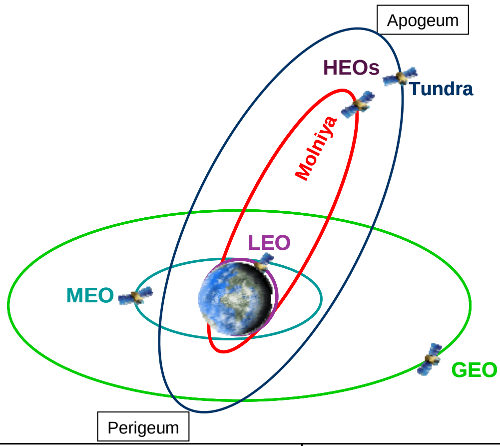


Figure 3 Wireless terrestrial systems evolution roadmap

3.2 *SatCom systems*

MarCom's objective is to find appropriate SatCom solutions to complement terrestrial technologies, mainly beyond their coverage - and the most suitable are hence being sought among systems utilizing GEO, LEO and HEO orbits (see Figure 4).

A GEO satellite appears to be in a fixed position to an earth-based observer, since it is revolving around the Earth at a constant speed once per day at an altitude of about 36.000 km over the equator. 3-4 satellite constellations are generally used to obtain nearly 'global' coverage - however excluding a.o. the polar regions (!).



Orbit	Height [km]
LEO: Low Earth Orbit	200 – 2.000
MEO: Medium Earth Orbit	2.000-GEO; normally: 10.000-20.000
GEO: Geostationary Orbit	35.786
HEO: High Elliptical Orbit	500-50.000

Figure 4 Satellite orbits and their main features

Inmarsat is internationally recognized as pioneers in mobile satellite services, being founded 30 years ago to ensure that ships could stay in constant touch by telephone via GEO satellites.

Over the years Inmarsat has continued to introduce new technologies and services, particularly to the maritime community: Inmarsat-A, -B, -C, -M, Mini-M, GAN, -D/D+, MPDS and the Fleet family (Fleet77, 55 and 33), based on older technologies termed "Existing and Evolved", mostly providing fax/data services with rates up to 9.6 kbps and medium/'high' speed data up to 128 kbps.

Recently Inmarsat introduced the novel BGAN concept, which benefits from the new I-4 satellites to offer a shared-channel IP packet-switched service of up to 492 kbps, and a streaming-IP service from 32 to 256 kbps. The BGAN family includes Fleet Broadband, a service planned for ships and the maritime community.

Another GEO-based alternative is represented by the various VSAT systems, utilizing satellite stations with typically dish antennas smaller than 3 m in diameter (most VSAT antenna diameters ranging from 75 cm to 1.2 m) to obtain data rates generally from narrowband up to 4 Mbps (46 Mbps being presently the fastest one [7]).

DVB-RCS represents a novel broadband VSAT-type multi-user design included in the Digital Video Broadcasting (DVB) family, and thus being the only open international standard for satellite networks with two-way communications, providing high capacity towards user (~40 Mbps downlink) and more moderate capacity from user (~2 Mbps uplink). DVB-RCS technology allows for star and mesh topologies with 10.000's of VSATs per network. Over 100 DVB-RCS systems are operating worldwide today - going mobile with handover from satellite to satellite, and numerous trials including train-, aircraft- and vessel-mounted terminals.

The only seemingly interesting LEO alternative is the Iridium constellation, using 66 cross-linked satellites in near polar orbit inclined 86.4° to the equator at an altitude of 780 km - and accordingly an orbit period of about 100 minutes - providing allegedly 'true' global coverage.

The nominal data rate of an Iridium 'channel' is 4.7 kbps, with latency for data connections about 1.8 s (round-trip) using small packets [8]. Iridium is also advertising a "Direct Internet" at 10 kbps, but this throughput is seemingly attainable only with compressible data subjected to Iridium's proprietary (remote) compression software.

The recent service offered by Iridium is OpenPort, claiming IP-based data rates of 9.6 -128 kbps (configurable), featuring allegedly global gap-free, pole-to-pole coverage, with low-profile omnidirectional antennas independent of stabilization platforms.

Iridium is also planning a new generation of satellites - 'Iridium NEXT', to be operational by 2016, and expected to provide date speeds up to 1 Mbps (transportable K_a-band up to 10 Mbps (?)) [9].

Contrary to GEOs and LEOs the HEOs are characterized by a relatively low-altitude perigee and a high-altitude apogee. These elongated orbits have the advantage of long dwell times near a point in the sky during the approach to and descent from apogee - a phenomenon known as the 'apogee dwell' in accordance with Kepler's second law. The orbital eccentricity is adjusted to the rotation of the Earth in order to make the satellites operating near the apogee and moving with nearly the same speed as the Earth, thereby maintaining a fixed position in relation to a point on the ground.

During the early 1960's Soviet Union aerospace engineers devised the Molniya HEO, which is simulating the convenience of a GEO while simultaneously servicing the extreme northern regions, having an inclination of (ideally) 63.45° with respect to the Earth's equatorial plane, and an orbital period of ½ a sidereal day. During this orbital period the Earth makes ½ a turn, and thus the apogeum will be at the very same position relative to earth twice a day. Seen from the Earth a Molniya orbit satellite will thus apparently be in zenith about 39.750 km above two positions (at latitude 63.45°- see Figure 5) during roughly 8 hours twice each day, the perigee height being only about 500 km. Accordingly 2 satellites would provide continuous coverage of the northern hemisphere, but a 3-satellite constellation is preferable [10].

Apart from the evident Russian applications, several studies on utilizing Molniya orbits for quite a few applications have been carried out, recognizing their apparent benefits in:

- Providing a quasi-stationary perspective with an apogee height approximating the GEO, and thus GEO technologies can be reused (slightly modified) to a.o. reduce costs and risks
- Giving an optimum high-latitude coverage per satellite with no LEO-like latitudinal coverage gaps, and little time "wasted" over lower latitudes adequately seen from GEOs
- Simple ground segment; real-time communications can be achieved with a single primary ground station, as for GEO
- More cost-effective than GEO systems for the delivery of satellite-based mobile multimedia in Europe [10].

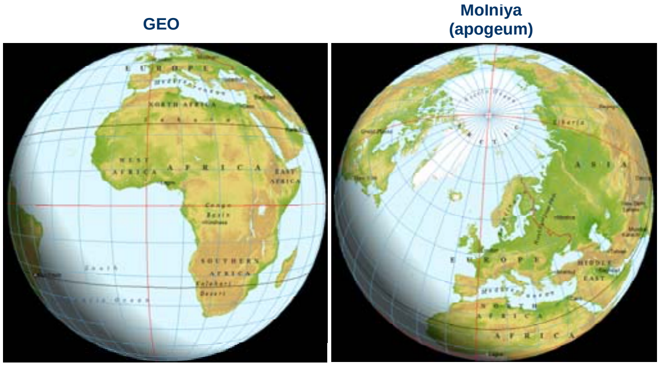


Figure 5 The Earth seen from GEO and HEO (Molniya) satellites, respectively

However, an inconvenience with the Molniya orbit is its satellites passage through the 'van Allen radiation belt' twice per revolution, requiring additional mass to obtain protection of e.g. the solar panels.

Another attractive HEO avoiding this hindrance is the more low-eccentric '24-hours' Tundra orbit, which is more comprehensively described in [1].

4 THE HIGH NORTH CHALLENGES

The fragile environment of the High North is decidedly dependent on a sustainable ecosystem balance. Safeguarding this balance calls for a highly developed communication infrastructure and sophisticated surveillance systems, which are presently unavailable. Reliable broadband radio communications in the Northern and Arctic Region is vital for fast reporting of status and evolution of the environment, and early warning of pollution threats. Additionally, these technologies are decisive for efficient handling of hazards and accidents intimidating people and/or the environment.

Broadband radio communications with data rates of several Mbps is anticipated to be needed by several activities in this vast area, out of which the more important are:

- Fisheries, including resource investigations and protection
- Oil and gas offshore activities
- Fishfarming, aquaculture installations and associated activities
- The Coast Guard's law enforcement of environmental crime and other illegal activities
- Homeland security and defense activities

- Research activities (ice studies, meteorological and hydrological research and monitoring etc.)
- Coastal water activities (ferries, cruise ships, support ships, fishing, fishfarming etc.)

The terrestrial systems outlined in paragraph 3.1.1 needs further thorough investigations regarding feasible utilization in the High North, but the commercial aspects are most likely to override the technical challenges, since the initial number of users are supposed to be fewer than commercial operators would consider satisfactory.

However, our preliminary findings indicate the coastal areas (including the Northeast and Northwest passage) to be adequately covered by terrestrial systems, where sub-GHz WiMAX and enhanced D-VHF are considered the most promising alternatives. In order to cover the passage North of Russia or Canada, or the area near Svalbard, a "chain" of pertinent base stations with an appropriate backhaul infrastructure would be required. The cost and complexity of such a system would necessitate a detailed study of a.o. the area's topography. But even if such systems could be favorably deployed, vast areas would still be left uncovered, demanding other solutions to complement these coastal area systems.

The crucial limitations of traditional SatCom systems are illustrated in Figure 6:

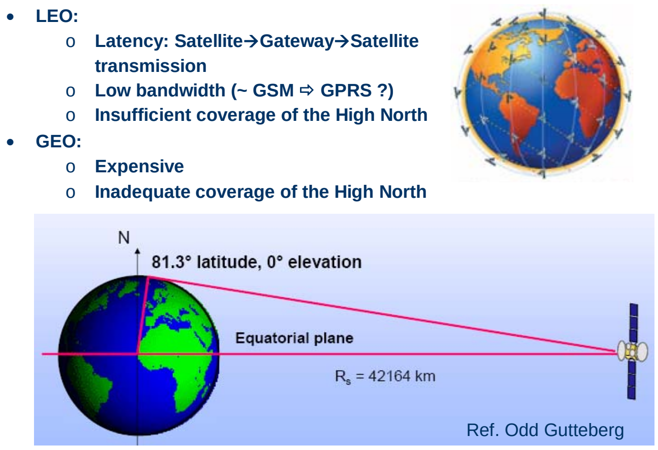


Figure 6 Traditional SatCom limitations in Polar regions

- Although Iridium claims the OpenPort service to provide IP-based data rates of 9.6-128 kbps, featuring allegedly global gap-free, pole-to-pole coverage, this system is judged inadequate as a more permanent solution to the High North
- GEO satellites are invisible at latitudes exceeding about 80° N
- Even relatively advanced maritime SatCom terminals with stabilized antennas require elevation angles preferably >5°, and are thus rendered inadequate at latitudes exceeding about 76°N
- Stabilized antennas must lock onto the intended satellite for proper operation, but several conditions, including the vessel's unpredictable gyrations, can instigate a stabilized antenna to drift from the intended satellite and cause signal drop-out and/or harmful interference to adjacent satellites. Due to rather severe roll, pitch and yaw movements of a vessel during adverse weather conditions even larger elevation angles are required, and thus practical problems with 'standard' SatCom terminals may be expected to arise at latitudes beyond about 70°N. Layers of (mixed) saltwater, sleet and ice on the antenna radome will certainly not diminish such problems, and thus adding up to the unsatisfactory situation illustrated in Figure 7.

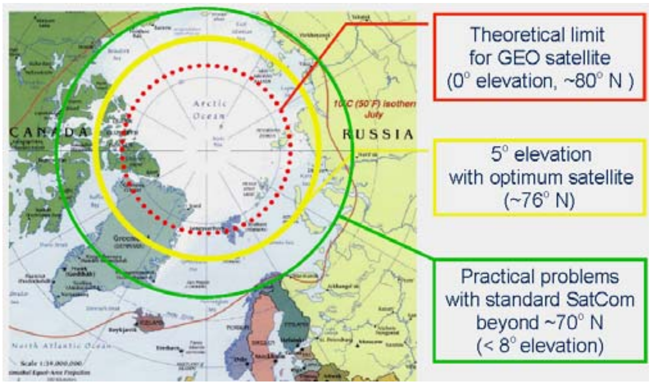


Figure 7 Illustration of the inadequate GEO coverage in the High North

Consequently it seems evident from our preliminary findings that HEO's would provide the only technically viable alternative for adequate SatCom's in the northern areas - in fact to the northern hemisphere on the whole (which accordingly also applies to the southern hemisphere if the orbits are 'reversed'). However, thorough investigations are required to reveal the cost/performance figures of pertinent systems, along with their success factors [1].

5 RADIO ENGINEERING CHALLENGES IN MARITIME ENVIRONMENTS

In order to meet MarCom's major objective of extending the coverage and range at sea for both in-use and novel terrestrial wireless technologies, several radio engineering challenges are to be met, such as:

- The characteristics of radio signal propagation over the sea must be known
- Appropriate frequency resources must be (made) available
- Improved antenna systems need careful attention
- Investigations of additional means to extend the coverage and range are required, such as:
  - Repeaters; passive, active and regenerative
  - Mobile Multi-hop Relay (MMR)
  - Mesh networking

The ability to accurately predict radio propagation behaviour for wireless services is becoming crucial to system design. Numerous studies have (unsurprisingly) been conducted for densely populated areas, but very few have been focusing coastal waters, exhibiting physical layer structures quite dissimilar to urban surroundings. Consequently reliable radio channel models for propagation over sea are required to make appropriate range/coverage predictions, and particularly to enable improvements of system performance by applying e.g. diversity and/or advanced antenna systems techniques. Both theoretical studies and experimental trials are required to determine such models.

The overcrowded radio frequency spectrum represents a crucial challenge to wireless services in general, and to maritime applications in particular.

However, ITUs World Radiocommunication Conference 2007 (WRC-07) approved the identification of the 450-470 MHz and 698-862 MHz frequency bands for International Mobile Telecommunications (IMT) services. These frequency bands are being referred to as the 'digital dividend' - the freeing up of spectrum brought about by the terrestrial TV distribution switch from analogue to digital technology.

These frequencies are also being referred to as a part of "the spectral sirloin", since, in addition to exhibiting attractive propagation characteristics, they also facilitate relatively undemanding development and low-cost production of RX/TX radio equipment with reasonable size and weight. The upper UHF band (698-862 MHz) is thus a target band for the WiMAX Forum, and the earliest applicable (reconfigurable) sub-GHz WiMAX products are already commercially available [5].

The utilization of these sub-GHz frequencies would facilitate the novel wireless terrestrial systems extension of coverage and range at sea, which is illustrated by the fact that e.g. covering the same area require only 2 base stations at 450 MHz compared to 30 at 3.5 GHz - i.e. also an economical advantage factor of about 15 (!) [5] - thus being highly beneficial to maritime applications.

However, each country has the authority to manage their frequency resources, and an international harmonization would consequently be needed to provide the maritime community with the most favourable solution.

Antennas (and RF transceivers) comprise crucial sub-systems to any radio system. Numerous antennas presently being applied in wireless systems are rather outdated, and accordingly system performance can be significantly enhanced by utilizing more sophisticated antenna designs. Emerging smart antenna technologies also enabling cost-effective shipborne solutions represents an area to which extensive R&D resources should definitely be allocated.

Other means of enhancing range/coverage are Repeaters (both passive, active and regenerative), Mobile Multi-hop Relay (MMR) and Mesh networking, all referring to different concepts for conveying user data, and possibly controlling information, between a base station and a mobile station through one or more relay units - to be utilized along with the other appropriate techniques and methods discussed in this paper to realize the suggested 'Wireless Coastal Area Network' (WiCAN) concept illustrated in Figure 8 [1].

Figure 8 Illustration of the suggested 'Wireless Coastal Area Network' (WiCAN) concept

In order to facilitate seamless and continuous handover and roaming within the heterogeneous WiCAN environment, a 'smart mobile router' would represent a crucial component, having been termed an 'Agile MarCom Communication Adapter' (AMCA) in the MarCom project.

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