TECHNICAL NOTE

HYBRID COMMUNICATION NETWORK FOR THE PURPOSE OF MARITIME APPLICATIONS

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SUMMARY

The article presents the concept of the hybrid communication system for the purpose of maritime applications. The main idea of this system is that it will utilize the seamless roaming concept, which means the communication link at sea will be established automatically (and seamlessly for the user), using many possible communication techniques (cellular, LTE, Wi-Fi, VDES, etc.) which will be selected depending on the current conditions of the radio channel and the requirements and preferences of the user. The paper will introduce the general architecture of the system, the concept of the maritime cloud and the seamless roaming, including the way the latter will be implemented in the system. The authors will also briefly introduce the proposed test-bed of the system's on-board device. The system presented in the article is one of the major topics of the EfficienSea 2 project (co-funded from the 'Horizon 2020' programme) in which the authors of the paper participate.

NOMENCLATURE

AIS	Automatic Identification System
MC	Maritime Cloud
MCC	Maritime Cloud Client
VDE-SAT	VHF Data Exchange - satellite
VDES	VHF Data Exchange System
VSAT	Very Small Aperture Terminal

1. INTRODUCTION

One of the vital aspects of modern navigation is providing ship with means for reliable and high-quality communications and data transmission. Data transmission between ships or between a ship and a shore-based entity is of particular importance given the recent growth of e-navigation services which are supposed to improve the safety of navigation. Traditional methods of communication at sea might not be sufficient to satisfy the requirements of those services and the users' preferences. In a long-term perspective it might prove necessary to employ systems and technologies that are not usually associated with maritime applications such as mobile networks, WiMAX, Wi-Fi, etc.

In 2015, the EfficienSea 2 project [1] – partly funded from the European Union's Horizon 2020 research and innovation programme – was initiated. The project has 32 partners from countries in the Baltic Sea region and beyond and its general goal is to co-create and deploy innovative solutions for safer and more efficient waterborne operations. One of the subtasks this project is dealing with is a development of the concept, prototype implementation and conducting tests of a maritime hybrid communication network. The main concept of this solution assumes that various radio communication systems are integrated into one network, and the information and data can be routed by the most feasible or lowest cost communication channel. The selection of the communication link to be used in a given moment will be performed by sophisticated algorithms called seamless roaming in order to meet user requirements and/or the nature of the requested services.

It is also assumed the hybrid communication network will be compatible with the recently developed concept of Maritime Cloud (MC) [2]; all the services and other functionalities of the network will be provided by the MC.

The following paper will introduce the projected architecture of the hybrid communication network and the purpose of its components. It will also present and explain the major algorithms to be utilized in the concept, especially those connected with the seamless roaming functionality. Finally, the authors will discuss a test bed that is currently being developed and that will be used in the testing process of the network in real conditions (i.e. at sea).

2. HYBRID COMMUNICATION SYSTEM

2.1 GENERAL CONCEPT

The hybrid communication system – developed in the EfficienSea 2 project – is to provide access to several services offered via Maritime Cloud. The main concept of the system is based on the assumption that connections are set up automatically using different radio interfaces, and the current interface is selected from those available by sophisticated algorithms taking into account a number of parameters, including user's preferences. In other words, ships will be able to switch automatically and seamlessly between different communication technologies (cellular networks, satellite systems, AIS, VDES, etc.) to allow information distribution between ships and between ships and shore-based users depending on the link availability and other factors considered by the relevant algorithms. Those algorithms will be addressed later in this paper.

In Figure 1, the architecture of the hybrid communication system is presented.

2.2 ARCHITECTURE

The hybrid communication system is comprised of three main segments:

- The coastal segment,
- The onboard segment,
- The satellite segment.

The coastal segment covers the infrastructure of the radio networks, whose technical parameters and base stations' locations enable the communication between users at sea. In particular, this segment comprises:

- Cellular networks (2G, 3G, LTE),
- VDE-Terrestrial (work underway),
- Other (might potentially become part of the coastal segment), such as:
  - WiMAX networks,
  - Wi-Fi networks (only in the vicinity of ports – due to limited operating ranges of these networks).

Satellite segment covers satellite systems that successfully provide communication links on areas where terrestrial systems are unable to do so. In particular, this segment comprises:

- VDE-SAT (work underway),
- VSAT,
- Other commercial satellite data transmission systems.

It goes without saying, it is way beyond the scope of the EfficienSea 2 project to modify or alter the infrastructure of the coastal and satellite segments, so in the following section, we will mainly concentrate on the description of the onboard segment.

The onboard segment includes systems and interfaces installed on board of the ship. Those systems and interfaces enable communication via coastal/satellite infrastructure and also direct ship-to-ship communication (under the condition all involved ships are equipped in compatible interfaces and are sufficiently close to one another). It is assumed direct communication can be carried out via a VDE Ship-to-Ship link or using Wi-Fi networks at 2,45 GHz or 5 GHz. The data obtained from the AIS system (position and bearing of the neighboring ships) allow to identify those ships with which a direct ship-to-ship communication is possible. Additionally, the AIS data help to calculate distances to the neighboring ships which is one of the factors that determines which technology might be used for this ship-to-ship communication. It should also be added that e.g. Iridium system or the MF/HF data services can be used for direct communications as well.

3. MARITIME CLOUD

Maritime Cloud can be defined as a communication framework enabling efficient, secure, reliable and seamless electronic information exchange between all authorized maritime stakeholders across available communication systems. It is a novel concept created by the engineers coordinated by the Danish Maritime Authority (DMA) [2] and developed in several European projects (e.g. Mona Lisa 2 [3] and ACCSEAS [4])

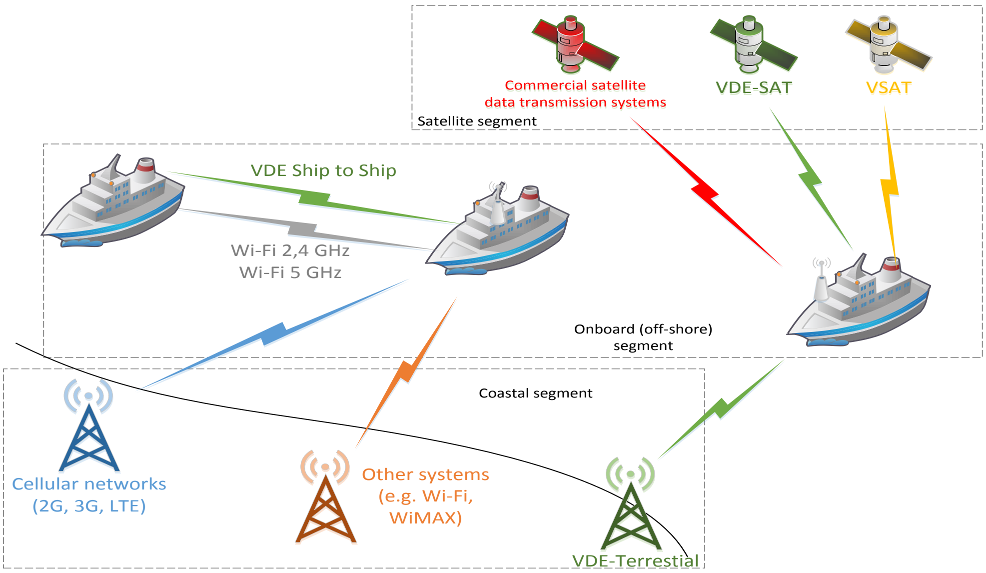

Figure 1: The architecture of the hybrid communication system.

The core of the MC comprises registers with information about available services and about the "actors" (i.e. ships, ship owners, shore-based entities) that might be involved in the maritime communications. The Maritime Cloud services will be provided to ship/coastal applications via the so-called Maritime Cloud Client. This component will enable a proper operation of the Maritime Cloud services – independently of hardware elements – by providing roaming between various data transmission systems. This is why it has been previously stated that the hybrid communication network will be compatible and will have to cooperate with the Maritime Cloud. The layer architecture of the Maritime Cloud Client is shown in Figure 2. This illustration also indicates the components of the hybrid communication network responsible for the seamless roaming.

The layers presented in the figure have the following functions:

- **Application layer** - The application layer consists of:
  - Ship and shore side applications offering functionality to users.
  - Applications providing maritime services.
  - Components offering services to applications.
- **Maritime Cloud layer** - Encapsulating complexities of communication and offering an interface to Cloud functionality.
- **Geo-messaging protocol** - A geo-aware messaging protocol on top of Internet transport protocols.
- **TCP/UDP/IP** - Internet protocol (IP) and transport protocols TCP and UDP. Through the use of Multi-WAN routers the layer will be able to select among a number of physical links.
- **Link layer** - A number of link layer protocols using physical means. E.g. mobile broadband, SAT, WiMAX.
- **Non-Internet communication systems** - A number of communication systems each consisting of different layers. Each communication system will have a set of properties, e.g. bandwidth, range and abilities of the communication system.

The blocks of the radio link selection and network monitoring (indicated in Figure 2) are the "core" of the seamless roaming concept, and their detailed description will be provided in the next paragraph. These two elements constitute the so-called "roaming device".

As we can see, Figure 2 clearly distinguishes a separate category of non-internet communication systems (i.e. systems which are not based on IP protocol), e.g. AIS or VDES [5]. Potentially, both group of systems (i.e. TCP/UDP/IP systems and Non TCP/UDP/IP systems) may also contain novel and anticipated solutions, e.g. those developed currently in other research projects. Each of those systems may have different architectures and different sets of parameters, including transmission bandwidth, range or achievable throughputs.

Additionally, the proposed concept assumes than an IP-based signaling channel between Maritime Cloud layer and the device responsible for roaming will be utilized (as it is indicated in Figure 2). This channel is necessary mainly because the MCC is almost at the top of the layer model (below the application layer, to be precise) and the roaming device requires a lot of data from higher layers, such as:

- Information that will ultimately translate into the actual selection of the radio link;
- High level user preferences – which are essential for the roaming algorithm;
- High level AIS and GPS data – to be used by both the roaming device and roaming algorithm.

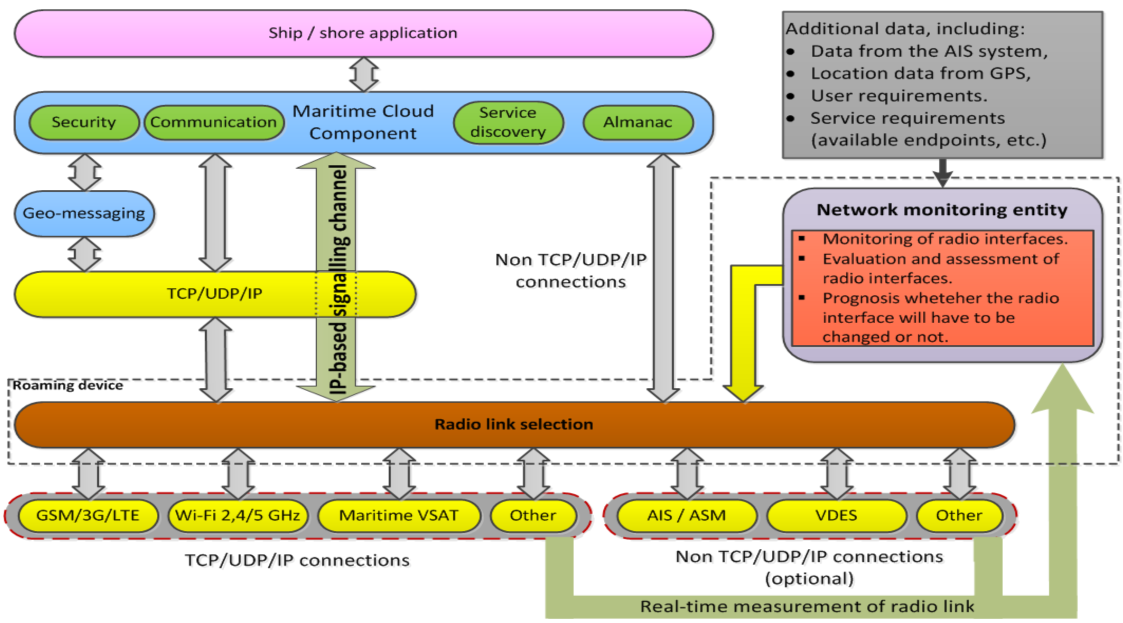

Figure 2: The architecture of the Maritime Cloud Client with the components of the hybrid communication system and the seamless roaming.

The proposed signaling channel, which will be based on TCP/UDP protocols, will be capable of sending the above data and, if necessary, commands between the MCC and roaming device. From the technical point of view, a specific port number might be utilized for the latter purpose.

4. SEAMLESS ROAMING

Definitely one of the most important elements of the future hybrid communication network is the seamless roaming (Shenoy & Montalvo 2005, Park 2004), which is a mechanism where the most suitable (for the given service, in the given time and place) radio link (interface) is selected from among all that currently are available at the vessel. The main task of the seamless roaming is a constant monitoring of the available radio links and switching between them to ensure optimal (given the selected set of criteria) conditions for the required maritime services. The seamless roaming algorithm will also address user's preferences, e.g. minimization of the transmission duration or minimization of the transmission costs.

In the following sections, the seamless roaming algorithm will be discussed and the major components of the hybrid system responsible for the seamless roaming functionality (the network monitoring entity and the radio selection block) will be introduced.

4.1 GENERAL ALGORITHM OF THE SEAMLESS ROAMING

The seamless roaming will work according to the algorithm depicted in Figure 3.

The first step of the algorithm presented in Figure 3 is the initial selection of the radio network/system that may be suitable for the given service. This initial selection is done on the basis of the service's profile, implemented policies and/or user's preferences. After that, the availability of those networks/systems is verified, which is followed by setting up the actual connection to enable and initiate the service required by the user. An example of how the typical seamless roaming mechanism is executed is presented in Figure 4.

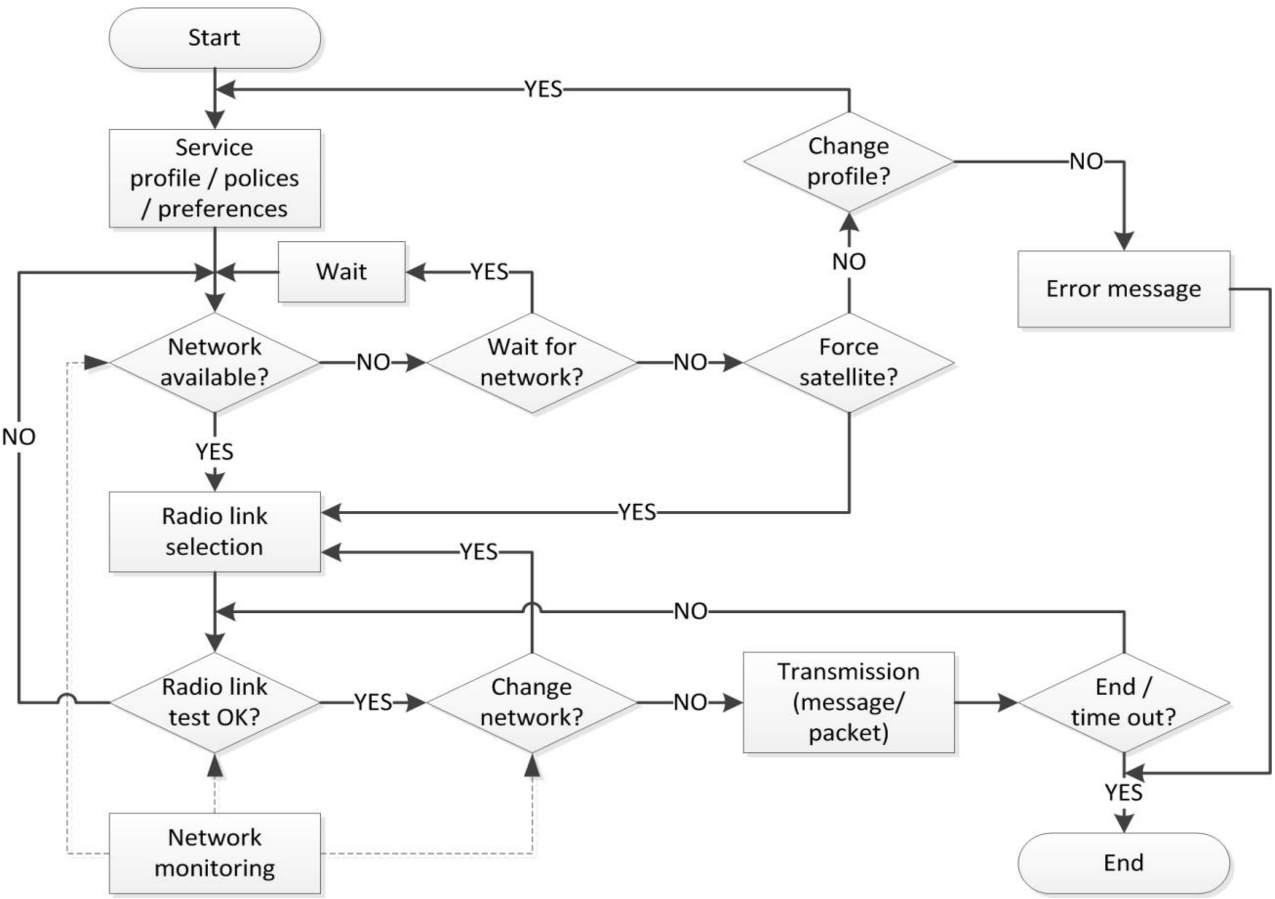

Figure 3: General algorithm of the seamless roaming mechanism.

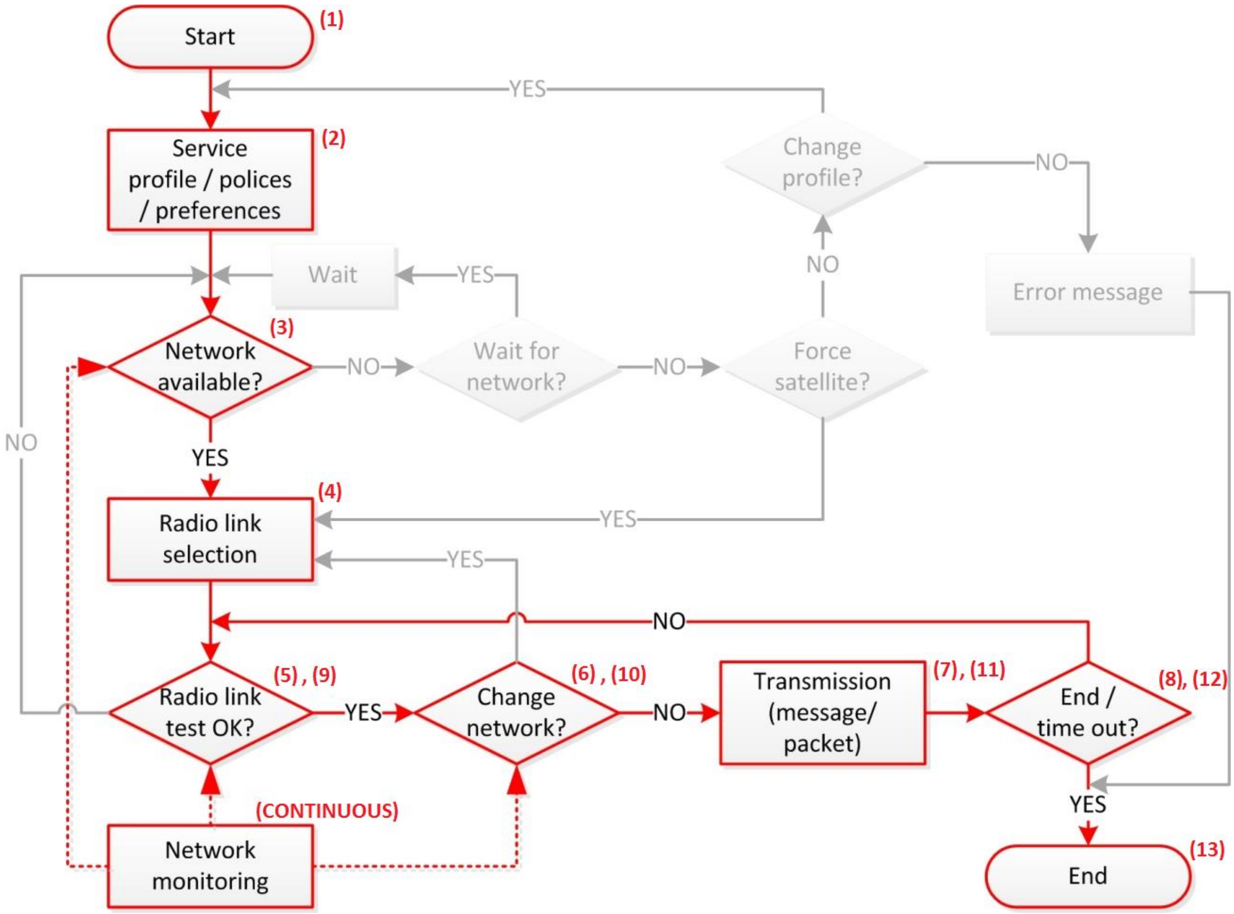

Figure 4: An example scenario of using the seamless roaming mechanism.

During the transmission, its quality is periodically measured and if necessary, a switching might take place (i.e. the network/system currently utilized might be replaced by another network/system in order to improve transmission quality or to ensure the initial quality criteria can be satisfied). The frequency of those tests may depend on the frequency of packets/messages transmission or it may be constant. If the network monitoring entity determines the network switching should occur, the algorithm will carry out this order. If during the transmission its quality drops so dramatically that the current service cannot go on (e.g. a vessel goes beyond the range of the terrestrial systems), then the availability of all radio networks/systems has to be rechecked. If – at a certain moment – none of those networks is available but additional information (e.g. from the GPS) indicates our vessel should shortly restore its connection with terrestrial systems (or the ship-to-ship communication can be employed), the algorithm may go into standby mode until the connection is actually restored. On the other hand, if the service has a high priority and no delays are acceptable, the transmission could be realized via satellite links which are available almost at all times (but at the same time they also very expensive and for this reason are not a viable option in typical scenarios). If the service's preferences explicitly prohibit utilizing satellite links, the algorithm will inform the user about the possibility of changing those preferences or will report transmission error.

4.2 NETWORK MONITORING ENTITY

The network monitoring entity is an important component of the seamless roaming mechanism and it is responsible for periodic quality tests of the available communication systems. The monitoring of the radio links is conducted both during data transmission (i.e. when a service is being carried out) and when the system is in stand-by mode (waiting for another task). The frequency of those tests will depend on the radio system type, utilized equipment, etc. For complex systems that are capable of switching between different radio links, only a single link quality assessment will be performed.

The radio links testing will be based mainly on the measurement of radio signal level and on the analysis of the broadcast network quality parameters (which can be obtained without setting up the actual connection with the network). In case of satellite systems, the capability of setting up the connection using satellite links depends on the current ship's location, so the testing of those links simply comes down to verifying if the ship can be "seen" by satellites of the analysed system.

The information provided by the network monitoring entity are used to make decisions by the radio link selection block, which is described below.

It should also be added, the information provided by the network monitoring entity might give knowledge about the 'neighbors' and the quality of their connections. The term 'neighbors' is very general and in this case might have several meanings: it could represent a nearby ship, a nearby base station or any relevant element of the radio communication link. The knowledge of the neighbors and their current state allows to develop relevant self-organization and routing algorithms, and consequently to implement mesh network-based solutions which potentially could prove advantageous for the future hybrid communication system.

4.3 RADIO LINK SELECTION

Alongside the network monitoring entity, the radio link selection is a second major element of the seamless roaming mechanism. Generally, it is responsible for selecting the optimal method of transmission in the given time and place on the basis of the information on networks' availability and performance (provided by the network monitoring entity) and then – if required – for switching between various data transmission technologies. It should be underlined, the procedure of radio link selection and (perhaps) switching will be carried out periodically during the connection (not just once when the connection is set up), because the availability and quality of radio networks will vary both in time and place.

For the implementation of the discussed block it is crucial to establish link selection criteria, as they will serve as a base for every decision about selection/switching of the radio link. The radio link selection criteria that have been defined up to this point are as follows:

- Radio signal power level,
- Data rate,
- Transmission delay,
- Predicted duration of the link availability,
- Required (maximum) time during which data must be transmitted,
- Amount of data to be transmitted,
- Transmission costs,
- Priorities of the service/user,
- Defined list of endpoints for a given service.

The above information – or at least some of them – will serve as an input to the link selection algorithm that is being developed now and whose initial concept is presented in the subsection 4.4.

It should be noted that one of the issues that might arise during the channel switching is the overhead, i.e. the time required to establish a new connection. In some scenarios this overhead might be unacceptably long and render the whole concept of switching virtually useless. One of the options to counter this effect is to keep all the available connections, while obviously using only one of them. For example, let us assume a ship in a given moment of time is in the range of both the Wi-Fi network and the 3G network. For the purpose of transmission the ship utilizes the Wi-Fi, but it also maintains the connection with the 3G network. Consequently, when the ship moves out of range of the Wi-Fi, the process of switching to 3G will be very fast and the whole overhead will be kept to a minimum.

4.4 WEIGHTING ALGORITHM FOR THE RADIO LINK SELECTION

For a set of various maritime services (and also for the same service utilized by different users with different preferences) some radio link selection criteria may be more important than the others. For this reason it has been decided the most suitable solution will be a weighting radio link selection algorithm.

The main assumption of this concept is that both the user and the services have priorities and preferences that should be processed by the algorithm. Obviously, not all of those priorities and preferences have to be equally important. Consequently, for a certain service, a set of most important parameters (from among the radio link selection criteria) will be defined, and then each of those parameters will be assigned a weight coefficient. Additionally, to give user more freedom, it will be possible to modify (within reasonable limits) some of those parameters.

The weight coefficients will be obtained empirically during the implementation phase. Additionally, a metric will be developed, to facilitate a final decision which of the available radio links is the most suitable for a given application.

Below, we provide a few examples of how the weighting algorithm could work in typical scenarios.

Scenario 1 – service: data transmission, priority: minimum transmission costs.

Key parameters and their respective weight coefficients:

- Transmission costs – 0.6;
- Predicted duration of the link availability – 0.2;
- Data rate – 0.1;
- Radio signal power level – 0.1.

Scenario 2 – service: data transmission (large file), priority: maximum data rate.

Key parameters and their respective weight coefficients:

- Data rate – 0.6;
- Predicted duration of the link availability – 0.2;
- Radio signal power level – 0.1;
- Transmission costs – 0.1.

Scenario 3 – service: data transmission (small file), priority: minimum transmission duration.

Key parameters and their respective weight coefficients:

- Predicted duration of the link availability – 0.7;
- Data rate – 0.2;
- Radio signal power level – 0.1.

It should be noted that if the predicted duration of the link availability has a higher priority (i.e. greater weight) than the data rate, then the system can select e.g. the VDES system, even though the UMTS might be available as well, because the VDES link will typically be available longer and there is much smaller risk that the radio link switching during transmission will be necessary.

5. HARDWARE MODEL OF THE HYBRID COMMUNICATION SYSTEM

At the time of this writing, the final concept of the hybrid communication system is being refined; simultaneously, the work on the test-bed of the system's on-board module has been initiated. In this paragraph, we shall briefly introduce the initial architecture of this model which will – in the further stages of the EfficienSea 2 project – be utilized for the purpose of the resulting system measurements and testing.

It has to be underlined that the concept presented below is not a concept of an actual, commercial device ready to be installed on-board and used in operational conditions; it is merely a laboratory prototype which offers a full functionality, but is designed strictly for the purpose of the upcoming tests.

Additionally, at this stage, no human interface will be proposed, since the presented implementation will be used mainly by the engineers (during the tests) rather than by the target users.

The general architecture of the proposed on-board module test-bed is depicted in Figure 5a.

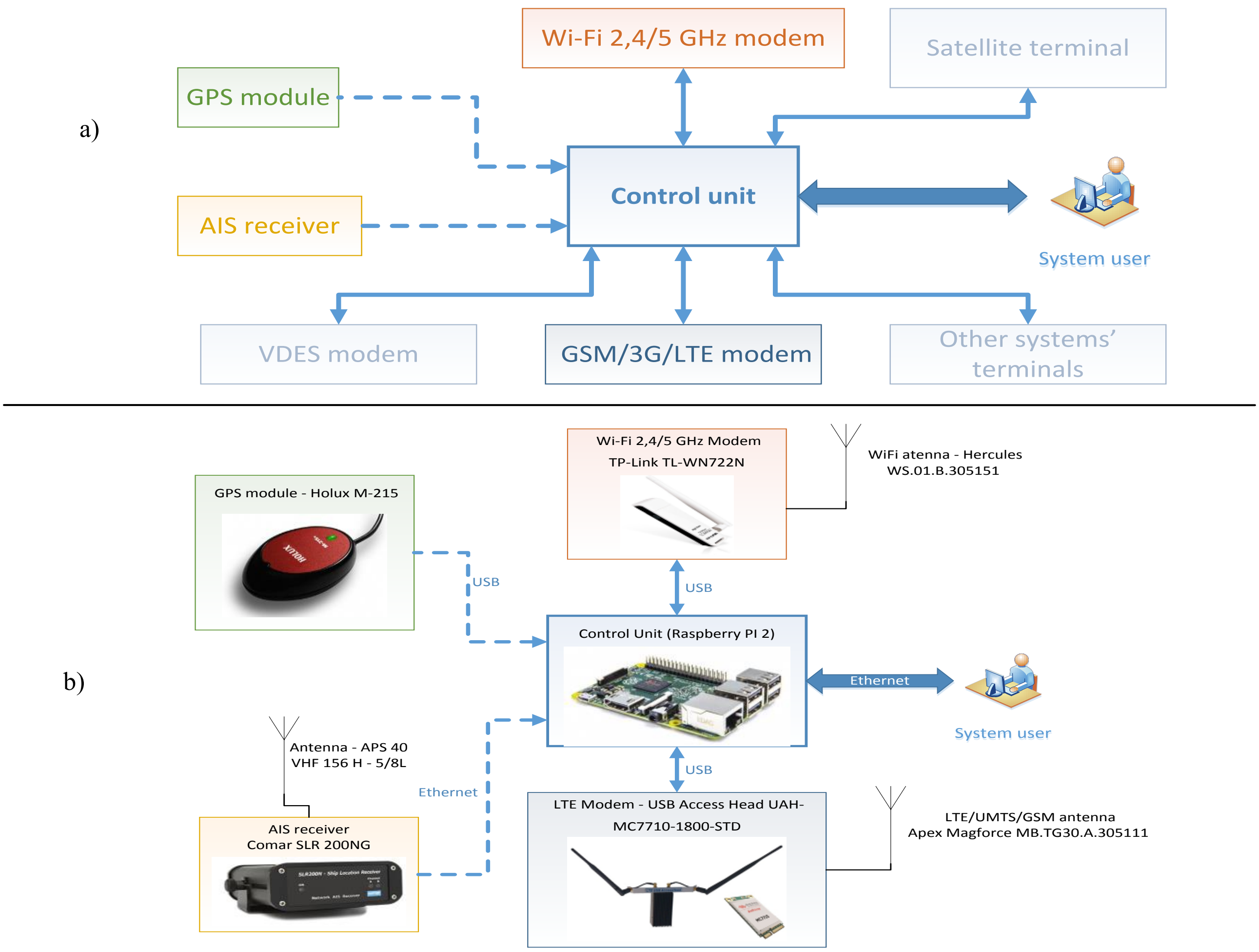

Figure 5: The on-board module test-bed: (a) general architecture, (b) proposed hardware implementation.

The central component of the onboard module is the Control unit. It is responsible for several functions, i.e.:

a) configuration of the module's segments and verification if they operate correctly,
b) monitoring of the radio links and switching between them,
c) setting up the connection link via one of the available radio interfaces.

Additionally, the prototype will comprise devices that support the following technologies: GSM/3G/LTE, Wi-Fi 2.4 / 5 GHz, AIS and GPS. Possible integration of the VDES module depends on the date when VDES-devices (commercial ones or prototypes) come into market. A support for other systems such as VSAT or WiMAX is also anticipated.

Up to this point, the authors of the article have selected all the hardware elements necessary to build the presented prototype. This concept has been presented in Figure 5b.

6. CONCLUSIONS

The hybrid communication network as proposed in this paper could be a significant improvement of ship-to-ship and ship-to-shore connectivity, especially in the context of services that require higher data rates. The concept of the network is obviously in the initial stage and further work is closely correlated with the time schedule of the EfficienSea 2 project. It is anticipated that by the end of this year, the hardware test-bed on the system's module will have been up and running and several measurement campaigns will have been performed. Those campaigns will be conducted both in laboratory as well as in real conditions (at sea), and their purpose will be a verification of the implemented algorithms, and identifications of areas for improvement. Additionally, during the measurements the parameters of the radio link selection algorithm will be empirically determined (see paragraph 4.4).

It should also be noticed that several elements the hybrid system is comprised of are being developed independently of the EfficienSea 2 project. It applies particularly to the concept of the Maritime Cloud and the VDES system. The first one is currently specified by the engineers from the Danish Maritime Administration (DMA), whereas the work on the VDES system (which might become one of the major maritime communication standards) is continued in such bodies as IALA and ITU. Up to this point, the so-called 'Release 0' of the VDES standard [5] was published which describes the concept and assumptions of the system but cannot be a basis for building actual radio equipment. The first version of full VDES standard is due to be published in 2017. The outcome of these activities (MC and VDES) could ultimately affect the final form of the hybrid communication system and the results of the EfficienSea 2 project in general.

7. ACKNOWLEDGEMENTS

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