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Optimizing Data Traffic Route for Maritime Vessels Communications

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Abstract

The growing demands for data links capacity in maritime vessels and high costs of satellite communication links through mandatory GMDSS Inmarsat equipment emphasize the possibility of optimizing data traffic routes through alternative service providers either satellite or terrestrial. Lower cost services, as well as increased link capacity will justify introduction of new technologies onboard ships. Implementation of new technologies is important, but also the appropriate implementation of processes and the awareness and motivation of the people on board that ensures the value of such a service. In order to realize more convenient link, the development of a mathematical model is proposed as basis for decision making optimization of data traffic route in communication of maritime vessels. In addition to the presentation of previous research, the paper also shows the optimization of data traffic route by the example of authentic maritime communications within the organizational environment.

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Keywords: GMDSS; data traffic; ship's communications; routing traffic; cost optimisation

1. Introduction

International Maritime Organisation (IMO) initiated International Convention for the Safety of Life at Sea (SOLAS) after the Titanic disaster as the first set of international standards to enhance maritime safety that came into force in 1929 [1]. IMO SOLAS ships sailing on ocean routes have mandatory International Maritime Satellite

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(INMARSAT) terminals. Those terminals used onboard ships must fulfil SOLAS regulations. Therefore, the Global Maritime Distress and Safety System (GMDSS) was structured. Inmarsat mandatory terminals are capable of providing TCP/IP data link speeds up to 2x64kbit/s by means of INMARSAT B or INMARSAT Fleet77 terminals using I-3 INMARSAT (3rd generation) satellite network [2]. More recent INMARSAT I-4 (4th generation) Broadband Global Area Network (BGAN) satellite network paired with Inmarsat Fleetbroadband FBB500 onboard terminals provide speeds up to 492kbit/s [3]. This year INMARSAT started a launch process of future constellation three I-5 satellites that will provide download speeds up to 54Mbit/s.

Very Small Aperture Terminal (VSAT) companies provide the key role in existing broadband maritime market. Those VSAT networks use higher band frequencies than Inmarsat I-3 and I-4, and that leads to less expensive bandwidth. The main disadvantage of this system, in addition to low ocean coverage areas, is excessive sensitivity to rain (the link is not usable during rain).

Although GMDSS has no mandatory terrestrial data links technologies do exist via WiFi or WiMAX in the third or fourth generation [4], [5]. Speeds vary from several Mbit/s and unlimited data plans are available.

The aim of the paper is to provide an overview of existing research studies and their approaches concerning the optimizing of data traffic route and to introduce mathematical model concept that would implement optimal routing of data traffic for maritime vessels communications in the range from expensive satellite links to capacity unlimited and less expensive terrestrial links.

This article presents the analysis of availability period for terrestrial and satellite links by means of example of an actual voyage by the container ship OOCL Netherlands on her voyage 30W34 in 2012 on Atlantic route for each hour of the voyage [6], [7].

It must be considered that a data link could be established in three different ways: terrestrial, satellite VSAT or satellite Inmarsat link, for modelling purpose. An authentic voyage data measurement shows the time of link availability in port, or approaches to the port. Information regarding rain was available from ship's log. In case that ship's log does not include rain data, it is possible to use data based on forecasting numerical model available [8]. When rain occurs, VSAT link becomes unavailable, Inmarsat link is always available but it is the most expensive one.

2. Previous research

The idea of routing data from satellite links to terrestrial links technique is not new. Technologies are not inter-compatible and ideas of complementing satellite with other terrestrial communication technologies have been considered in [9] and [10]. Several possible approaches or techniques to solve the problem are given. A possible solution is generating ad hoc networks [10] and [11]. The rapid growth of terrestrial mobile data systems has resulted in a large number of new services offered to mobile users. Maritime shipping market has the same growing demand [9]. Another approach is given in terms of reducing the workload of data 3G/4G network routing and re-routing traffic to WiFi networks [12] and [13].

European space agency ESA has developed a project called Satellite Based System and Services for Broadband Applications at Sea - Sass@sea service which is providing two-way IP connections between ships at sea and the shipping companies ashore. When the ships are outside of the VSAT coverage, the user traffic is switched to alternative maritime satellite systems like Inmarsat or Iridium. Within coastal areas or in ports, 3G/4G mobile networks or WiFi hot spots can also be used to deliver high volumes data [14] and [15].

Research studies of onboard communications implemented hybrid (satellite-terrestrial) ship communication network by means of analyses and simulation. There are two key aspects of this proposal: first to combine different onboard communication networks into a hybrid system, enabling the cooperation between them, and second is to smoothly integrate these networks with a consideration of backward compatibility, ease of deployment and connection to shore via Internet [16].

Other research studies have analyzed coverage extension of the high bit rate terrestrial links to ships. Link is achieved by forming a mobile wireless mesh network using mesh networks amongst neighbouring ships, marine beacons and buoys by means of ad hoc network standards such as Mobile Ad Hoc Network MANET and Vehicular Ad Hoc Network VANET [17].

In order to achieve better network performance in high seas maritime cognitive wireless networks approach is proposed and implemented in [18].

Routing protocol called maritime two-state (MTS) protocol for maritime multi-hop wireless networks presented in [19] provides efficient and reliable communication with a minimum of overhead. A WiMAX mesh wireless network in a maritime communication environment is used in simulation. Two states protocol is represented by beaconing state and prediction state. The network model considered for the simulation is a general maritime network which covers narrow navigation channels and traffic separation scheme defined by the IMO [19].

A cooperative spectrum sensing scheme for maritime cognitive radio networks (MCRNs) with the optimized *m*-out-of-*n* rule, the entropy-based detector and energy detector for desired ranges of sea states were analysed in simulation shown in [20].

Further research development lead to Aero routing protocol AeroRP establishment, a geographic-based routing protocol designed specifically for high-speed environments of MANET aircraft networks [21].

Clear solution to Quality of Service (QoS) in communication networks does not exist [22].

Maritime e-navigation is based on ICT in order to support integrated operation of ships [10] should be compatible to existing solutions described in [23] and [24]. In order to implement new technology onboard ship, Bridge Team Management that assures the safety of navigation, meaning also the safety of crew onboard, and at the same time, the safety of the ship and cargo onboard must be considered [25].

3. Technical proposal

Terrestrial links costs versus satellite links costs justify the existing data and phone traffic reroute from expensive Inmarsat satellite link to less expensive VSAT link and to cheaper terrestrial links in their coverage zones, respectively. The cost of installation of non-mandatory equipment on board must be financially justified.

Gateways to satellite links can be redirected directly on router to terrestrial links whenever link is available. The link for ship to shore direction will be rerouted onboard ship in accordance with link availability and preference delivery, higher priority to terrestrial link is given.It is possible to predict the link availability in shore to ship direction by means of application written in Matlab for Markov chain. Markov chain represents a mathematical system that undergoes transitions from one state to another on a state space and can be used to predict the next state which depends only on the current state and not on the sequence of events that preceded it.Nowadays, technical solutions are given for satellite rerouting by service provider that gives integral link to Inmarsat and VSAT service. Such solution is given by KVH company, for example [26].

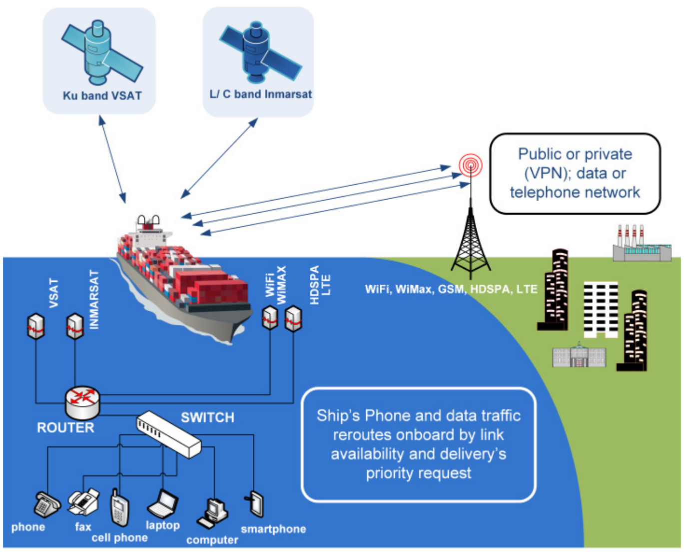

Fig. 1. Routing Internet traffic

Although for system shown in Fig. 1 solution does not exist yet, it should be considered.

3.1. Internet link example

In example shown in Fig. 2, internet access is possible by means of satellite or terrestrial equipment. The cost of terrestrial links is least expensive, but service is available only in ports or when a ship approaches the port, which is up to 20 nautical miles distance from the ship to coastal infrastructure.

Access to internet using satellite infrastructure is possible worldwide on sailing routes of merchant shipping, but access is very expensive. Inmarsat availability is global between 70°N and 70°S latitudes, but with the highest cost. VSAT technology has a reasonable cost, but level of availability is lower. Link coverage is one limitation and rain attenuation is another one.

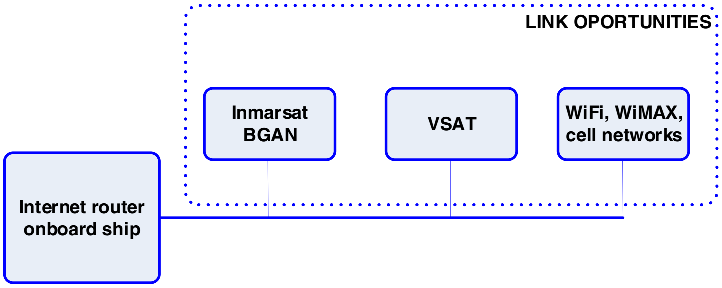

Fig. 2. Data link opportunities onboard ocean going ships.

While the ship is in port, several cellular networks or high capacity networks such as WiFi or WiMAX links are available. That emphasizes a potent role of wireless terrestrial high speeds and capacities networks in harbour surroundings and growth of significance and distribution of those technologies for operational use. It is very likely that ships entering the ports will use that infrastructure even more. Many ports are already offering commercial services such as internet connectivity for crew and passengers to ships over a wireless network based on WiFi (e.g. Port of Antwerp) or WiMAX (e.g. Port of Singapore.) Satellite links are acceptable for less intensive applications. Favourable circumstances are that ship's demands for communications regularly increase when ship approaches the port or in the very ports. The main reason for such results is that communications due to logistic needs are intensive and higher safety or operational reporting requirements still remain.

Access to communications networks that provides less expensive communications by means of access links to large capacity networks such as WiFi or WiMAX, enhance onboard crew welfare and morale, as sometimes the importance of crew welfare can be underestimated. Better levels of service LoS that terrestrial links offer compared to satellite links (e.g. smaller latencies) provide application of real time communications such as voice over internet protocol VoIP and video conferences. Hybrid structure consisted of terrestrial links would lead to favourable cost to volume ratio in ports and when ships approach ports with satellite links, on high seas and places where terrestrial infrastructure is out of range.

4. Analysis of coverage times on North Atlantic ATX route by means of terrestrial and satellite links

North Atlantic route of container ship OOCL Netherlands on Atlantic Express ATX voyage was analysed in [27]. Internet traffic routing from satellite to terrestrial service providers was justified due to the fact that significant voyage time was covered with terrestrial links zone coverage out of total time. Route analysed was ATX route: Rotterdam - Hamburg - Le Havre - Southampton - New York - Norfolk – Charleston –Rotterdam [27].

In this paper, the data on indicated time when rain occurred was taken from the Ship’s log. This data define states that are needed for mathematical modelling of random events of probability of one of three possible states as shown in Fig. 2.

For dynamic modelling in the ITS environment, it is important to know the actual values of traffic variables and real time operation.

Gathering data and processing speed of traffic data and system response to changes must be such as to ensure the manageability of the system and prevent problems.

Data obtained by measuring, or by forecasting numerical model of the probability of rainfall occurrence, can be used to produce a matrix of transition probabilities. It is possible to use the method of mathematical modelling of stochastic process in which the set T is discrete and set S is discrete and finite. This is defined by Markov model where next state of system does not depend on sequence of events that precede [28].

The formal definition of Markov chains states that the sequence of random variables X1, X2, X3, ... is called a Markov chain if the Markov property holds:

$$\mathrm{P}\left[X(n)\,|\,X(n-1),X(n-2),...,X(n-k)\right]=\mathrm{P}\left[X(n)\,|\,X(n-1)\right] \tag{1}$$

that is, future values of sequences depend only on the most recent value. Markov sequences are used to model the output of information sources that emit dependent sequences of symbols.

Markov chains are often described by a sequence of directed graphs, where the edges of graph n are labelled by the probabilities of going from one state at time to the other states.

Internet access from ship can be established by various systems presented in Fig. 1. Each system provides TCP/IP protocol needed for internet access.

In accordance with data collected from Ship's log from OOCL Netherlands on voyage 30W34 in 2012, Fig. 3 presents a timeline showing the position of the ship in port or at sea with rainy periods as indicated. The voyage started in July, 22nd 2012 and ended in August, 21st 2012 and lasted for 716 hours [27].

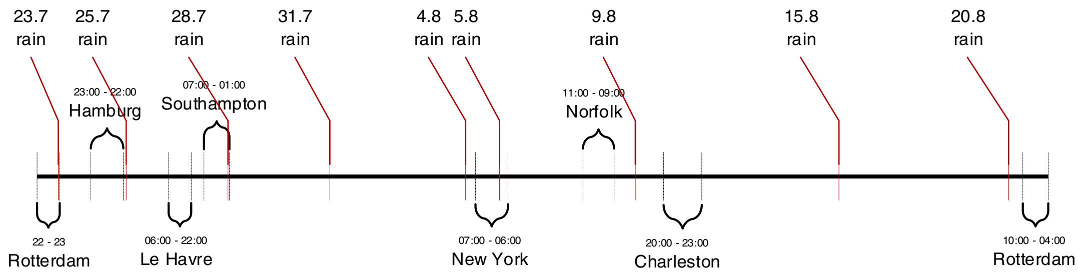

Fig. 3. The timeline of OOCL Netherlands voyage 30W40 in 2012.

System states can be defined in accordance with collected data:

- system state s1 is when the ship is in the range of terrestrial networks
- system state s2 is when rain occurs and the ship is out of range of terrestrial systems – only Inmarsat network and
- system state s3 is when the ship is out of range of terrestrial systems and VSAT network available

s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s2, s2, s2, s2, s2, s2, s2, s2, s3, s3, s3, s3, s3, s3, s3, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1, s1,
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Fig. 4. States count for OOCL Netherlands voyage 30W40 in 2012.

For the states shown in Fig. 4 it is necessary to define a system that may appear in series of events that could occur in one or more possible states.

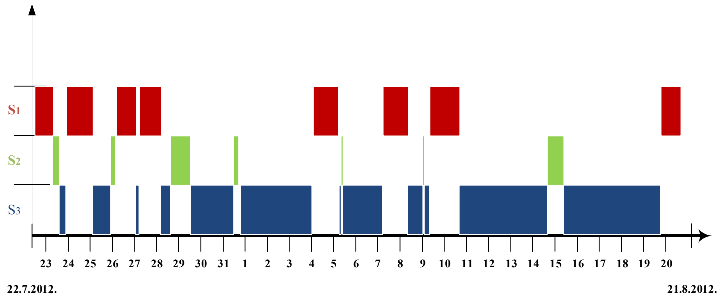

Fig. 5. State diagram for OOCL Netherlands voyage 30W40 from year 2012 timeline.

Transition states of system shown in Fig. 4. are colour underlined and summary is given in Table 1.

Table 1. Transition states analyses.

OOCL Netherlands, 30W34 yr. 2012			
transition	frequency	transition	frequency
s1,s2	1	s1,s3	5
s2,s1	1	s2,s3	6
s3,s1	6	s3,s2	5

Fig. 5 is shows that observed system states S={s1, s2, s3} is in defined set and it is possible to discern system states on the timeline (voyage estimated time 716 hours, respectively).

The information from Table 1 can be expressed in different ways. Fig. 6 is a transition diagram that shows the three states and the probabilities of going from one state to another.

The transition matrix for this example is:

$$P = \begin{array}{c} \\ s1 \\ s2 \\ s3 \end{array} \begin{array}{c} \begin{array}{ccc} s1 & s2 & s3 \end{array} \\ \begin{bmatrix} 0,2891 & 0,1185 & 0,5924 \\ 0,1297 & 0,0922 & 0,7781 \\ 0,2080 & 0,1733 & 0,6187 \end{bmatrix} \end{array} \quad (2)$$

Matrix P is regular transition matrix [10].

The first element of matrix P p_{11} shows that the probability of ship in terrestrial range (remain in state s1) is 28.91%. The second row contains an element of matrix P p_{22}, the link probability of Inmarsat satellite connection (remain in state s2) is 9.22%. The third row of transition matrix P shows that the probability of link established by VSAT (remain in state s3) is 61.87%

From transition matrix (2) it is possible to determine the state transition diagram presented in Fig. 6.

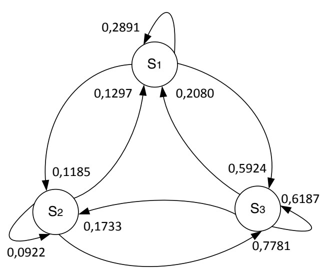

Fig. 6. State transition diagram on Markov chain for OOCL Netherlands on her voyage number 30W34 in 2012.

5. Conclusions

Reducing costs is a permanent process in the shipping industry. Implementation of new technologies onboard is one way to achieve that goal. Despite that, this paper has shown that reducing expenses can be achieved by implementing existing technology solutions in a new manner. Combining terrestrial service providers in ports (or approaches) with satellite service providers on high seas has in many cases proven financial justification.

Ship's demands for communications regularly increase when ship approaches the port, or when in ports.

Consequently communications due to logistic needs in ports are intensive and higher safety or operational reporting requirements remain. A considerable decrease of cost can be achieved by rerouting large volume data from satellite to terrestrial service providers.

The article presents the example of an authentic ship voyage data for container ship OOCL Netherlands on her voyage, number 30W34 in 2012. In the transatlantic route analyses it is shown that the ship was 27.8% of her total sail time in the range of terrestrial links. That availability of terrestrial links is supposed to be even higher on shorter voyages with more ports on the route. The paper shows the need for routing internet traffic on terrestrial providers away from expensive and volume limited satellite providers.

By means of applying Markov chain theory it is possible to build mathematical model of maritime vessel data traffic. It is also possible to optimize data traffic route by means of model based simulation in Matlab.

Future research could be realized by taking into consideration additional communication technologies such as TETRA for data link establishment and also higher availability of terrestrial infrastructure due to frequency band opportunity, as contribution of maritime safety and e-navigation, due to the fact that system is widely accepted in airports and seaports.

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