

THE CONCEPT OF BUILDING A WIRELESS OPTICAL COMMUNICATION NETWORK BETWEEN SURFACE SHIPS

E.G. Chulyaeva¹, S.N. Kuznetsov², B.I. Ognev²

¹Joint-stock company «Plasma», Ryazan, Russian Federation

²JSC «Mostcom», Ryazan, Russian Federation

The problem of organization of a wireless optical multi-node network (MANET) between surface ships has been considered. This type of connection can be an alternative to the classical radio message. The advantages of optical communication are faster data transmission, high security and immunity to interference. The goal of the work is creation of computer model of such communication network, a choice of an algorithm of the organization of logical network infrastructure and determination of the main technical requirements to optical communication terminals. The software “The emulator of a wireless optical network” was developed for simulation of the network of the moving surface ships. For the organization of a communication network the well-known algorithms of discrete mathematics (such as the Kruskal algorithm) were used. The simulation of the network was carried out; technical requirements to optical communication terminals as an element of the specified network were formulated.

Key words: wireless optical communication; free space optics; optical communication terminal; MANET

Citation: E.G. Chulyaeva, S.N. Kuznetsov, B.I. Ognev, The concept of building a wireless optical communication network between surface ships, St. Petersburg Polytechnical State University Journal. Physics and Mathematics. 11 (1) (2018) 50 – 55. DOI: 10.18721/JPM.11107

Introduction

There is currently a growing need for increasing the throughput of communication channels, including optical lines [1 – 8]; increasing the data transmission rate over communication lines is also important for design of communication systems between surface ships.

High-speed communication is needed not only between the ships, but also in communication between the ships and the shore and between the ships and aircraft for solving a wide array of problems, from aerial reconnaissance to the operation of communication systems in radio silence or with an increased level of interference (for example, electronic warfare). The quality of radio communications that are traditional in this segment does not meet the modern requirements to the data transmission rate.

On the other hand, high-speed microwave transmission over the water surface is complicated both by the conditions for propagation of radio signals over the conducting surface and by large angular deviations of the ship (motion and

maneuvering) relative to the angular sizes of directivity diagrams.

For these reasons, wireless optical communication is virtually the only solution to the problem of high-speed communication between surface ships. However, it is scarcely used at present due to some properties of this type of transmission and peculiarities of its applications.

In this paper, we consider the concept of constructing a wireless optical communication network between surface ships, starting from requirements for optical communication terminals, and dealing with algorithms for organizing a logical network infrastructure.

Problem statement

The main requirement for wireless optical communication is direct visibility between transceivers (optical communication terminals (OCT)). Line-of-sight range is substantially limited due to the curvature of the Earth's surface. For example, for an OCT installed at a height of 20 m, the line-of-sight distance is no more than 16 km.



Relatively small divergence angles of transmitter radiation and small viewing angles of OCT receivers significantly complicate the organization of a wireless optical communication channel between surface ships. As for transmitters, the requirement for narrow angular diagrams is due to the need to increase the margin for enhancing the optical power budget of a communication line. Reducing the viewing angles of receivers is necessary for minimizing their exposure to external radiation. The advantages of narrow angular diagrams of OCT transceivers are that adjacent OCTs practically do not affect each other and signal detection out of beam range is impossible (the communication channels are secure). The disadvantage of narrow diagrams is that additional instruments (such as charge-coupled devices (CCDs)) have to be introduced for searching, capturing and tracking subscribers while establishing and maintaining an optical communication channel.

Simultaneous requirements of wide coverage angles of the communication system and narrow viewing angles of the OCT entail using an optical beacon or a panoramic lighting system that allows each OCT to find all possible subscribers in the visible horizon.

In addition, while OCTs can be guided to each other manually for stationary applications (if they are fixed on a fairly steady support), CCD systems are absolutely necessary for moving and maneuvering surface ships.

Finding methods for deploying wireless optical communication networks is another major problem that needs to be addressed. These networks can consist of several mobile objects, with several point-to-point links with other objects organized on each of them. Due to the mobility of the objects to be connected and several directions of communication at each site, they have to be organized into a mobile dynamic (or ad-hoc) network, called MANET (Mobile Ad hoc NETWORK) [9].

Possible solutions of the problem

Based on the above-described equipment requirements, wireless optical communication devices should be used as OCTs, automatically searching for subscribers and capturing them (identification and establishing communication)

in a wide angular sector of the horizon (testing the ship's maneuvers) and with an elevation angle of at least $\pm 30^\circ$ (the ship's motion). Additionally, the subscriber has to be tracked in these conditions.

From the standpoint of organizing communication, the OCT control system of each ship should be able to determine the optimal configuration of communication directions and the operation mode of the ports connected to each OCT at each moment. In order to perform these tasks, the control system should have information about the location and spatial orientation of the ship's principal axis. Determining the optimal network configuration in MANET is a fairly complex problem [9, 10], and solving it considerably depends on the scenarios of application. For example, Ref. [9] considers the general case of configuring the network for use on various terrestrial terrain types, with aerial mobile objects and various types of communication (RF modules such as Bluetooth and Wi-Fi serve for data transmission in the VHF range).

Organizing wireless optical communication between sea ships is greatly simplified in the case under consideration because the dimensions of the connectivity domain are known (up to 20 km) and there is certain direct visibility between the ships.

The following procedures are necessary as a basic option of solving the task of building a network:

- determining all possible communication lines between the ships (based on the information on their location and orientation);

- constructing an optimal (spanning) tree of links between the ships;

- assigning the remaining available links as backup or parallel communication channels.

Based on possible scenarios, the above-mentioned link tree can be constructed not only with complete information about the location and orientation of the ship (which is not always available), but also using two other options:

- 1) based on a pre-designated central node (for example, a flagship);

- 2) by parallel construction of separate communication channels between adjacent ships, gradually integrating them into a common network.

Kruskal's, Prim's and Borůvka's algorithms are well-known methods of discrete mathematics that can be used for constructing the above-described spanning tree [11 – 14].

Simulation of the network configuration

The “Emulator of a wireless optical network” software was developed to simulate a network of mobile ships.

This software allows to arrange several ships on a plane with a given number of OCTs on each ship, specifying the position and orientation of each ship

The basic element in the model is a surface ship where optical communication terminals are installed, with working angles whose axes are pointing in opposite directions. The term ‘working angles’ here refers to horizontal fields of view containing directions on which communication can be established (including all three phases of communication: search, capture, tracking). A geometric model explaining the location of the ships with OCTs and working angles is shown schematically in Fig. 1.

According to the proposed model, each ship as a network object is characterized by the number of OCTs and their working angles.

This model assumes that it is possible to construct a graph of possible links between the ships by specifying their number, location and orientation.

Fig. 2 shows eight ships located on the simulation plane, with the OCT viewing angles and all possible communication links indicated.

Evidently, the set of possible connections between the ship is quite large. Constructing a spanning tree by Kruskal's algorithm (based on the complete data on the location and orientation of the ship) was carried out according to the flow chart shown in Fig. 3. The algorithm was modified for searching for a fail-safe edge. When analyzing each communication link, i.e., each candidate for connection to the network, not only a single node belonging to the network's connectivity component (‘security’), but also an edge equipped with free OCTs was taken into account

This algorithm was applied to building a communication network (Fig. 4).

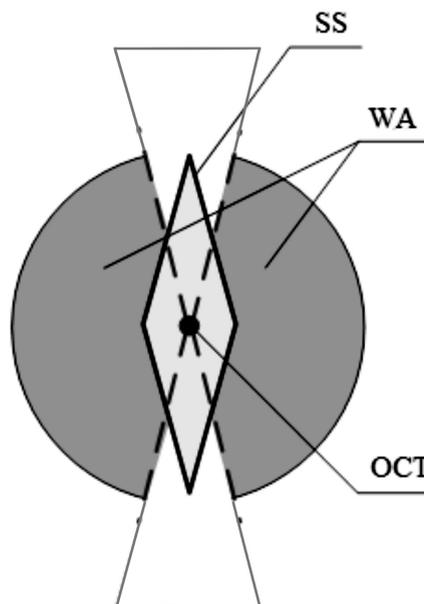


Fig. 1. Geometric model explaining the location of a surface ship (SS) with an optical communication terminal (OCT) and working angles (WAs)

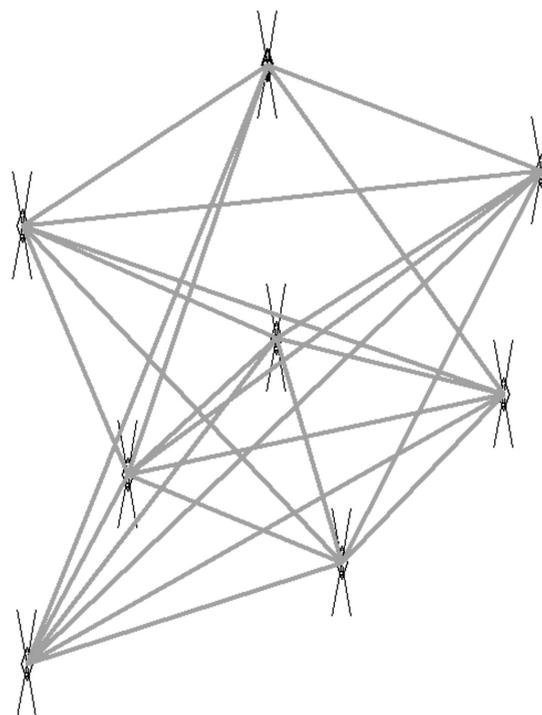


Fig. 2. Eight surface ships on the simulation plane of the “Emulator of a wireless optical network” software; OCT viewing angles and all possible communication links are shown

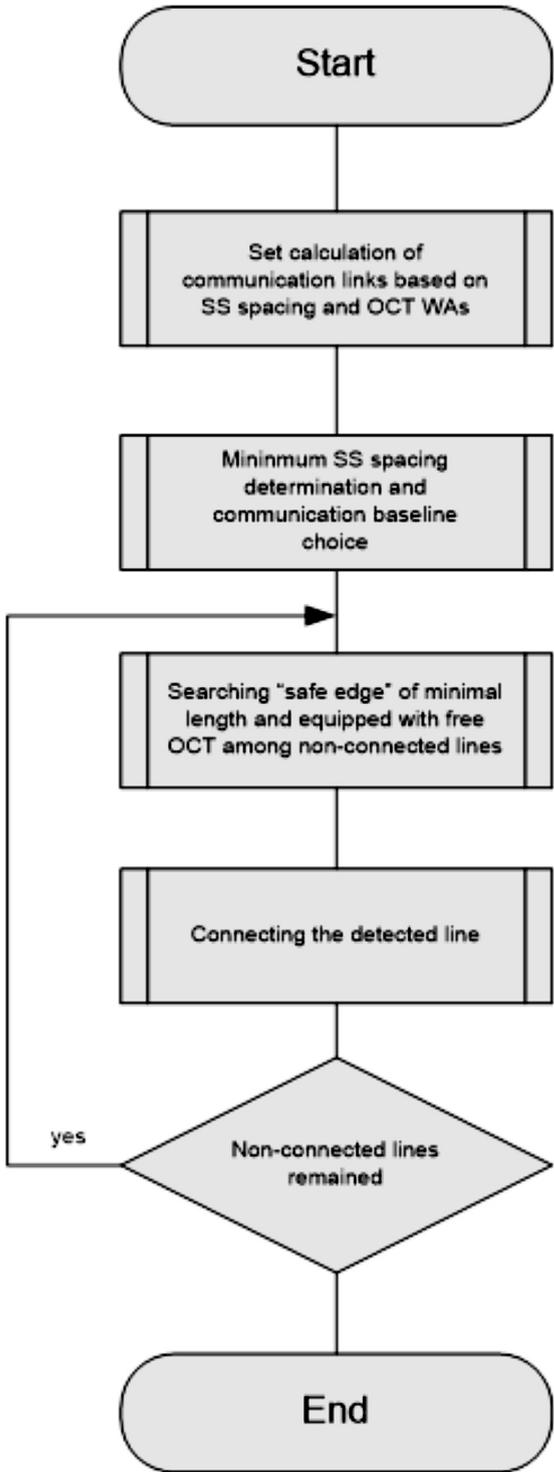


Fig. 3. Kruskal's algorithm for constructing a spanning tree of ship communication on the simulation plane of the EWON software; the algorithm is modified for searching for a safe edge

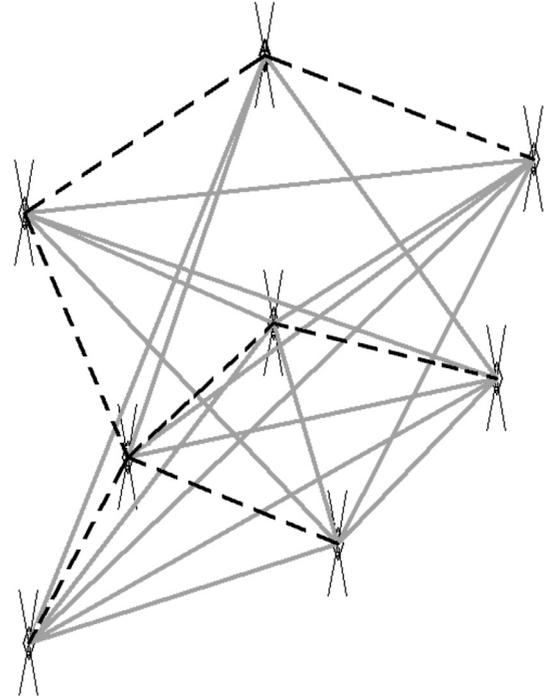


Fig. 4. A spanning tree of ship communication, obtained by Kruskal's algorithm (see Fig. 3); the main communication links are shown in dashed lines

Running Prim's and Borůvka's algorithms for the other two scenarios of building a communication network yields the same spanning tree (see Fig. 4). Unused links may remain in the spanning tree but it may still be possible to implement them (their number is what matters). The remaining possible communication links can be distributed with two purposes:

- for redundancy of already established communication links (parallel connections), integrating them into a single communication channel with load balancing;

- for organizing workarounds (unused loops) in order to improve the reliability of the network as a whole.

Thus, simulation of the communication network has confirmed that it is possible to create a wireless optical communication network between arbitrarily arranged surface ships taking into account their location and use of optical communication terminals that have finite working angles.

Based on the properties of the OCT and the methods of communication we have considered, we can formulate the main technical requirements for implementing the proposed network:

in search mode, panoramic lighting of the ship should be provided so that it can be found by its subscribers (the OCTs installed on other ships);

automatic guidance of the OCT should be developed in the tracking mode (after communication is established), compensating for all types of ship motion;

a central control unit (CCU) is required for all OCTs installed on one ship for the purpose of network configuration, routing, redundancy of communication lines and balancing of data

streams, as well as exchange of service information about the network status with the CCUs of other ships and integration with the local ship network.

Conclusion

In this paper, we have considered the problems of organizing a wireless optical multi-node communication network between surface ships. We have found the algorithms for organizing the communication network in three possible scenarios; these algorithms produce one configuration of a communication spanning tree. We have formulated the requirements for the technical means providing this communication network.

REFERENCES

- [1] Yu. Li, N. Pappas, V. Angelakis, M. Pioro, Yu. Di, Optimization of free space optical wireless network for cellular backhauling, *IEEE Journal on Selected Areas in Communications*. 33 (2) (2015) 1841–1854.
- [2] X. Rong, Y. Won-Hyuk, K. Young-Chon, Reconfigurable routing protocol for free space optical sensor networks, *Sensors*. 12 (4) (2012) 4824–4845.
- [3] M. Khalighi, M. Uysal, Survey on free space optical communication: A communication theory perspective, *IEEE Communications Surveys & Tutorials*. 10 (2) (2014) 1–22.
- [4] H. Zhou, A. Babaei, S. Mao, P. Agrawal, Algebraic connectivity of degree constrained spanning trees for FSO networks, *IEEE ICC*, 9–13 June. Budapest, Hungary (2013) 5991–5996.
- [5] D.M. Forin, G. Incerti, G.M.T. Beleffi, et al., Free space optical technologies, In: *Trends in Telecommunications Technologies*, Ch. 13, Ed. Ch.J. Bouras, Intech (2010) 257–296.
- [6] A.G. Alkholidi, K.S. Altowij, Free space optical communications: Theory and practices, In: *Contemporary Issues in Wireless Communications*, Ch. 5, Ed. M. Khatib, InTech (2014) 159–212.
- [7] V.S. Gurov, V.S. Zorkin, E.Yu. Gomozkova, et al., *Informatsionnyye lazernyye tekhnologii v promyshlennosti i sistemakh svyazi* [Informational laser technologies in industry and communications systems], Ryazan, Ryazan. State Radioeng. Un-ty, 2016.
- [8] V.S. Gurov, V.Yu. Mishin, E.G. Chulyayeva, *Lazernyye informatsionnyye tekhnologii* [Informational laser technologies], Lambert Academmic Publishing, 2017.
- [9] A. Dwivedi, P. Harshavardhana, P.G. Velez, D.J. Tebben, Dynamic topology optimization for assuring connectivity in multihop mobile optical wireless communications networks, *Johns Hopkins Apl. Technical Digest*. 30 (2) (2011) 151–167.
- [10] H. Kaushal, G. Kaddoum, Free space optical communication: challenges and mitigation techniques, *IEEE Communications Surveys & Tutorials*. 19 (1) (2017) 57–96.
- [11] A.I. Belousov, S.B. Tkachev, *Diskretnaya matematika* [Discrete mathematics], Moscow, MSTU, 2006.
- [12] D. Cheriton, R.E. Tarjan, Finding minimum spanning trees, *SIAM Journal on Computing*. 5 (4) (1976) 724–741.
- [13] D. Eppstein, Spanning trees and spanners, *Handbook of Computational Geometry* (1999) 425–461.
- [14] M. Mareš, Two linear time algorithms for MST on minor closed graph classes, *Archivum mathematicum*. 40 (3) (2004) 315–320.

Received 24.10.2017, accepted 06.11.2017.

THE AUTHORS

CHULYAEVA Elena G.

Joint-stock company "Plasma"

24 Tsiolkovskogo St., Ryazan, 390000, Russian Federation.
grp@plasmalabs.ru



KUZNETSOV Sergey N.

JSC "Mostcom"

6 Frunze St., Ryazan, 390046, Russian Federation.

ksn@mocskom.ru

OGNEV Boris I.

JSC "Mostcom"

6 Frunze St., Ryazan, 390046, Russian Federation.

develop@mocskom.ru