The Development of Soft Defined Distributed Infocommunication Systems Architecture Based on the Active Data Technology

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Abstract. The active data technology allows developing the architecture of soft defined systems based on the new principles. The most interesting implementation is to build self-organized networks that consist of UAV and robotic complexes. This paper is dedicated to the new architecture of mobile communication networks proposed by the authors. The analytical review of existing architectures of wireless self-organizing networks is given; research of available solutions' weaknesses allowed to put forward ideas for the development of a new concept. The proposed concept of node reconfiguration was developed; it helps to provide the required network structure with appropriate characteristics. The authors introduced the technology that was developed to organize a transmission channel for networks with mobile nodes based on the active data concept. The suggested architecture allows to arrange data transmission channels in the areas where it is difficult to deploy a network of ground communications nodes.

Keywords: Network · Architecture · Mobile distributed system · Mobile communications · Wireless self-organizing networks · Optimization · Active data concept

1 Introduction

In fact, the task of communication and the associated problem of data transmission is a key to eliminating situational ignorance in any mobile distributed system. This is especially true in the environment, when the user is in a remote place, not covered by the modern infrastructure of communication networks. In such cases, it becomes relevant to use a wireless data network, e.g., to provide a data transfer channel with mobile users; quickly deploy a network in the area not equipped with other telecommunication channels; provide data transfer in the area that is not suitable for the fixed infrastructure (water surface, highlands), etc.

Thus, the use of autonomous mobile communication centers (elements of a robotic technical complex) as repeaters or intermediate nodes in a data transmission network sets a problem of organizing their interaction in the context of continuously changing environmental factors. It is known that works in this sphere have been undertaken by

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large companies, for example, by Boeing (see reference [1]). Over the past decade, unmanned aerial vehicle (UAV) technology has significantly advanced in such areas as autonomous onboard processor's computing power, flight control, communications capabilities. Initially, due to the technical complexity of the implementation, UAVs were mainly used in the military sphere. However, with the progress of technology, the scope of applications has gradually expanded to other areas of activity: from agriculture, observation of large industrial facilities and rescue actions in emergency situations to the delivery of parcels. This makes it possible to use UAVs as small mobile platforms [2].

2 Existing Wireless Self-organizing Network Architectures

Let's consider the existing architecture and technology of building wireless self-organizing networks and their features.

By the definition given in the reference [3], mesh networks are networks with a mesh topology, consisting of wireless fixed (georeferenced) routers that create a data transmission channel and a service area (coverage area) of subscribers with access to one of the routers. The "STAR" topology with a random connection of reference nodes is used.

Ad hoc networks that implement decentralized control of random stationary subscribers in the absence of base stations or reference nodes are employed. A fixed network with random connection of nodes is used as the topology.

MANET

MANET (Mobile Ad Hoc NETworks) are the networks implementing fully decentralized management of random mobile subscribers in the absence of base stations or reference nodes.

Compared to traditional MANET networks, FANET networks (networks built on the basis of flying nodes) have a number of unique functions, such as high mobility and frequent topology changes that create problems for users in connecting to the network [4]. According to the reference [5], UAVs have a speed of 30–460 KPH. This raises the problem that the traditional routing protocols developed for MANET (for example, AODV, DSR, OLSR) cannot adapt well enough if they are applied directly to the FANET. As a result, it is extremely important to use a specialized reliable routing protocol specific to FANET [6].

FANET

FANET (Flying Ad Hoc Networks) self-organizing networks are ad hoc networks. The main difference of such networks from the wired ones [7] is that they are decentralized and have no routers, i.e., packets of information are sent on the fly, and Ad Hoc networks are routed dynamically. In reference [8] it is indicated that there are two main types of communication between UAVs in FANET networks.

FANET networks are networks for organizing the interaction of aircrafts =. Unlike VANET and MANET, they are distinguished by high mobility and rapid changes in the network topology. In such networks, there is an access point that provides traffic to all UAVs of the network. This is the advantage of FANET networks over other networks, since using points and channels can be reserved and, accordingly, the necessary distribution and traffic control.

The first FANET systems were implemented on the basis of the existing TCP and UDP network transport protocols [9]. However, as practice has shown, such protocols are poorly suited for data transmission.

JAUS

JAUS (Joint Architecture for Unmanned Systems) is an emerging standard for messaging between unmanned systems. The JAUS architecture has proven to be effective due to its active use in a large number of projects; for that reason, military, civil and commercial organizations plan to implement it in robotic complexes of various scales, including FANET networks [7, 9].

One of the emerging types of networks for controlling UAVs from the ground when interacting with FANET networks is sensor networks of WSN (Wireless Sensor Networks).

WSN

WSN (Wireless Sensor networks) are the distributed, self-organizing networks of multiple sensors and actuators, interconnected via a radio channel. The coverage area of such a network can range from several meters to several kilometers due to the ability to relay messages from one node to another. The combination of a sensor network and a FANET network assumes the presence of two segments: i.e., a ground and flying ones, which interact with each other. The ground segment, as a rule, is a distributed network of self-organizing sensory nodes [7, 10]. The flying segment represents one or more UAVs. WSN is a self-building system with many capabilities. For example, it can be transformed into a network capable of adapting to a changing external environment. Such adaptation is carried out by means of self-organized changes in the topology of network connections. The established intra-network rules (protocols) will ensure the reciprocal (shuttle) distribution of information in a heterogeneous network using the multi-hop method.

The dynamically adaptable WSN communications architecture is able to provide solutions for such tasks as attaching new nodes, expanding the spatial area occupied by the network, self-restoration (continuing the previous operation of the network in case of failure of individual nodes), etc. WSN can provide information gathering and data transferring over large areas for a long period of time.

In fact, all considered types of networks are an infrastructure for communication between nodes for solving the tasks of this group (in particular, FANET for organizing UAV interaction). As an implementation of a scenario for solving the problem of data transmission through a grouping of nodes as through a distributed infocommunication environment, we consider three options (strategies) for using UAV as a repeater:

(1) UAVs are advancing to predetermined positions in a controlled or unmanned mode and holding for the required time in hover mode [11];
(2) UAV are moving according to a predefined flight plane [12, 13];
(3) about group of UAVs in the mode of automatic search for locations most suitable for maintaining uninterrupted transmission is deploey with continuously changing environmental conditions taken into account [14–17].

Strategies 1 and 2 have been widely used for a long time in both military and civilian spheres; they have obvious limitations of applicability and, therefore, are of no interest for further consideration. Strategy 3 is a challenging task of ensuring interaction of multiple UAVs, which multiplies the workload of UAV operators in maintaining situational awareness, reducing their effectiveness, which, in its turn, leads to the loss of efficiency and possible incidents [13, 15]. Recently, several approaches have been proposed to ensure autonomous functioning of UAV groups, for example, the principles of swarm behavior [4].

In references [16, 17], methods for optimizing the mutual positions of several UAV repeaters with the aim of obtaining the required communication characteristics are considered. However, managing UAV groups is a challenging task for operators due to amplified workload and increasing situational awareness requirements. The operator has to assess the situation, make a decision and give the right control commands, while analyzing information flows coming from several UAVs at the same time. Information overload of the operator can lead to a decrease in the efficiency of work, and to potential emergencies.

In reference [18], the main problems of the organization of dynamic self-organizing networks based on mobile devices and methods for their solution are considered. It is indicated that the core issue is the definition of a data transfer route. Since the network topology and, moreover, the location of its nodes are irregular, determining the direction in which the receiving node is located becomes very difficult. To solve this problem, it is possible to propose several approaches to the construction of the architecture, which are distinguished by the complexity of implementation, on the one hand, and data delivery efficiency, on the other. The following approaches are applicable to transferring data to a static and mobile nodes:

- Static node is using devices without GPS module
- Static node is using devices with a GPS module
- Static node is based on statistical data on the relative location of network nodes
- Mobile node is using devices without a GPS module: (a) using an additional channel to transmit the coordinates of a node; (b) using statistical information
- Mobile node is using devices with a GPS module: using an additional channel to transfer the coordinates of a finite node; using statistical information about the relative location of network nodes
- Broadcasting.

In addition, many researchers focus on communication protocols and the organization of the network nodes interaction without focusing on the control of a single UAV or group of UAVs, while the specific location of the repeaters or the pattern of their movement often depends on the nature of the transmitted content and may change during the infocommunication session.

In general, all the considered methods of autonomous control of a UAV group are aimed at solving only one specific task, while the introduction of a software-defined technology in combination with the active data approach [19] to control of a UAV group can significantly expand the range of tasks and adaptability to environmental conditions due to the possibility of reprogramming network nodes on the fly.

3 The Concept of Active Data

The analysis of approaches and architectures has shown that most of the approaches are aimed at creating routing protocols and solving problems of traffic in mobile data networks optimization.

Developers offer new communication protocols and communication modules based on them, or use standard modules to build a mobile network, paying more attention to the behavior of network nodes.

Unlike analogous approaches, the authors propose to use an architecture that uses the active data approach [20, 21] (application of executable codes transmitted via data transfer channels and executed on communication nodes), which allows dynamic updating of a program component for the behavior of a group of UAVs (see Fig. 1).

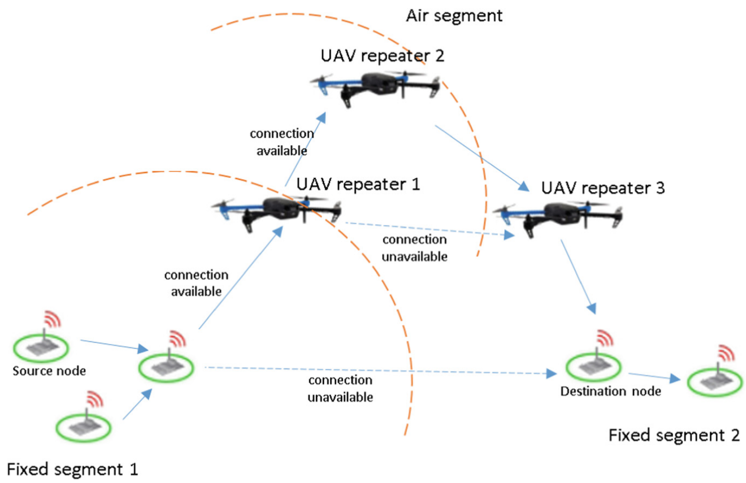

Fig. 1. Architecture of an infocommunication system based on a network with mobile nodes using the concept of active data (AD)

Active data (AD), according to [22], configure the software-defined equipment required for their propagation through the communication environment.

It is possible to distinguish the main groups of actions implemented by the means of the active data:

- Change of the operating frequencies, types of modulation or manipulation, topology of the network of radio devices through the re-initialization of communication modules
- Change of the data transfer formats, protocols, coding types by dynamically replacing the software component in communication modules
- Generating commands for changing the position of the UAV to control the spatial configuration of the repeater groups
- Reconfiguration of the flight controller by replacing the software component.

The listed action scenarios used in the tasks of information communication greatly increase the flexibility of data transmission channels based on mobile repeater networks.

4 Place of the Active Data in the UAV Control System

The proposed architecture partially changes the hardware structure of the UAV on-board equipment [23], as well as the software stack (see Fig. 2).

Let the flight plan be defined by the program, which determines not only the flight order for the given waypoints, but also the actions that need to be performed at these points or the allowed reactions to certain conditions that arise during the flight.

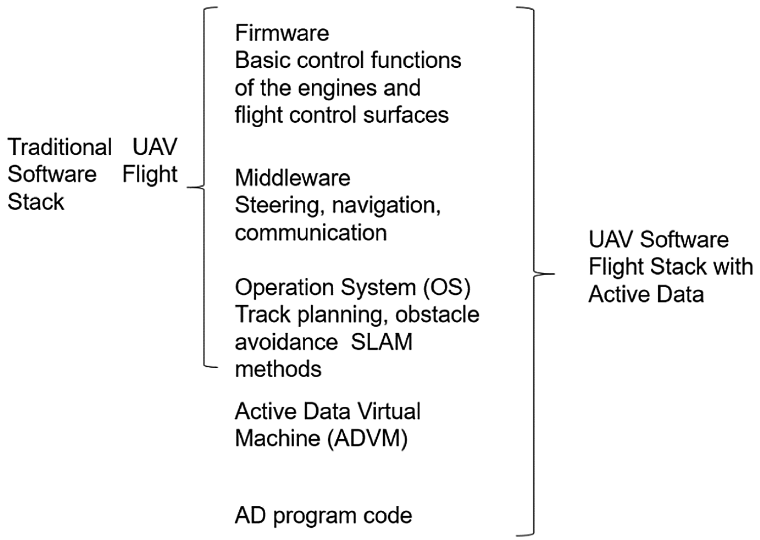

Fig. 2. UAV control system software stack

The use of an active data architecture makes it possible to control the behavior of a repeater UAV using the data flow which itself is allowing for a much greater functionality and scalability of the system.

5 Conclusion

An analytical review of existing architectures of wireless self-organizing networks, including the concepts and principles of MESH, MANET, and other distributed networks, showed that all considered types of networks are realizations of the communication infrastructure needed to solve the tasks of an autonomous mobile UAV network, and the researchers mainly concentrate on communication protocols and organizing interaction between network nodes without focusing on the reconfiguration of the network and its individual nodes.

To eliminate these shortcomings, a concept of node reconfiguration was developed to provide the required network structure with the required characteristics. To achieve this goal, a technology was developed to organize a transmission channel for the networks with mobile nodes based on the active data concept, which extends the range of possible operations due to active adaptation to changing conditions.

The proposed architecture provides for the organization of data transmission channels in the areas where it is difficult to deploy a network of ground communication nodes, as well as in emergency situations.

In contrast to the well-known works [1, 4, 6, 14, 24–27], it is proposed to use UAV controlled by AD as a mobile node where the software component of AD, being launched on each mobile node, analyzes the communication environment to make a decision on data delivery to the destination node.

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References

1. Quick, D.: Boeing demonstrates swarm technology. https://newatlas.com/uav-swarm-technology/19581/. Accessed 15 Apr 2019
2. Chmaj, G., Selvaraj, H.: UAV cooperative data processing using distributed computing platform. In: Advances in Intelligent Systems and Computing, vol. 1089, pp. 455–461. Springer, Cham (2015)
3. Pavlov, A.A., Datiev, I.O.: Routing protocols in wireless networks [Protokoly marshrutizatsii v besprovodnykh setyakh]. In: Proceedings of the Kola Science Center of the Russian Academy of Sciences [Trudy Kol'skogo nauchnogo tsentra RAN], vol. 5, no. 24 (2014). (in Russian)
4. Bekmezci, İ., Sahingoz, O.K., Temel, Ş.: Flying ad-hoc networks (FANETs): a survey. Ad Hoc Netw. **11**(3), 1254–1270 (2013)
5. Kuiper, E., Simin, N.-T.: Mobility models for UAV group reconnaissance applications. In: International Conference on Wireless and Mobile Communications (ICWMC 2006), vol. 33 (2006)
6. Li, X., Yan, J.: LEPR: link stability estimation-based preemptive routing protocol for flying ad hoc networks. In: Proceedings – IEEE Symposium on Computers and Communications (ISCC), Heraklion, pp. 1079–1083 (2017)
7. Kucheryavy, A.E., Vladyko, A.G., Kirichyok, R.V.: Flying sensor networks - a new Internet of Things App. Actual problems of information telecommunications in science and education. In: IV International Scientific-Technical and Scientific-Methodical Conference: A Collection of Scientific Articles in 2 Volumes, vol. 1, pp. 17–22 (2015). (in Russian)
8. Camp, T., Boleng, J., Davies, V.: A survey of mobility models for ad hoc network research. Wireless Commun. Mob. Comput. (WCMC) **2**(5), 483–502 (2002). Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications

9. Leonov, A.V., Chaplyshkin, V.A.: FANET networks. Omskiy nauchnyy vestnik **3**(143), 297–301 (2015). (in Russian)
10. Rusakov, A.M.: Model of flow control of measuring information of sensors in wireless sensor networks. Promyshlennyye ASU i Kontrollery **4**, 37–40 (2010). (in Russian)
11. Jawhar, I., Mohamed, N., Al-Jaroodi, J., et al.: Communication and networking of UAV-based systems: classification and associated architectures. J. Netw. Comput. Appl. **84**, 93–108 (2017)
12. Floreano, D., Wood, R.J.: Science, technology and the future of small autonomous drones. Nature **521**(7553), 460–466 (2015). https://doi.org/10.1038/nature14542
13. Samad, T., Bay, J.S., Godbole, D.: Network-centric systems for military operations in urban terrain: the role of UAVs. J. Proc. IEEE **95**(1), 4118473, 92–107 (2007). https://doi.org/10.1109/jproc.2006.887327
14. Lysenko, O.I., Valuiskyi, S.V., Tachinina, O.M., Danylyuk, S.L.: A method of control by telecommunication Airsystems for wireless AD HOC networks optimization. In: IEEE 3rd International Conference Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD) Proceedings, Kyiv, Ukraine, 13–15 October 2015, pp. 182–185 (2015)
15. Kirichek, R., Kulik, V.: Long-range data transmission on flying ubiquitous sensor networks (FUSN) by using LPWAN protocols. In: Vishnevskiy, V., Samouylov, K., Kozyrev, D. (eds.) Distributed Computer and Communication Networks (DCCN 2016). Communications in Computer and Information Science, vol. 678, pp. 442–453. Springer, Cham (2016)
16. Ono, F., Ochiai, H., Miura, R.: A wireless relay network based on unmanned aircraft system with rate optimization. IEEE Trans. Wireless Commun. **99**, 7562472 (2016). https://doi.org/10.1109/TWC.2016.2606388
17. Aksyonov, K., Antonova, A., Goncharova, N.: Choice of the scheduling technique taking into account the subcontracting optimization. In: Thampi, S.M., Krishnan, S., Corchado Rodriguez, J.M., Das, S., Wozniak, M., Al-Jumeily, D. (eds.) Advances in Signal Processing and Intelligent Recognition Systems, SIRS, Advances in Intelligent Systems and Computing, vol. 678, pp. 297–304. Springer, Cham (2018)
18. Shishaev, M.G., Potaman, S.A.: Modern technologies of ad-hoc type networks and possible approaches to the organization of peer-to-peer telecommunication networks based on mobile devices with a short range of action. Trudy Kol'skogo nauchnogo tsentra RAN **3**, 70–74 (2010). (in Russian)
19. Alexandrov, V.V., Kuleshov, S.V., Zaytseva, A.A.: Active data in digital software defined systems based on SEMS structures. In: Gorodetskiy, A. (ed.) Smart Electromechanical Systems. Studies in Systems, Decision and Control, vol. 49, pp. 61–69. Springer, Cham (2016)
20. Kuleshov, S.V., Tsvetkov, O.V.: Active data in digital software-defined systems. J. Informatsionno-izmeritel'nyye i upravlyayushchiye sistemy **6**, 12–19 (2014). (in Russian)
21. Alexandrov, V.V., Kuleshov, S.V.: Esterification and terminal programs. J. Informatsionnoizmeritel'nyye i upravlyayushchiye sistemy **10**(6), 50–53 (2008). (in Russian)
22. Tang, Y.-R., Li, Y.: The software architecture of a reconfigurable real-time onboard control system for a small UAV helicopter. In: 8th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), pp. 228–233. IEEE, Incheon (2011)
23. Kuleshov, S.V., Zaytseva, A.A., Aksenov, A.Y.: The conceptual view of unmanned aerial vehicle implementation as a mobile communication node of active data transmission network. Int. J. Intell. Unmanned Syst. **6**(4), 174–183 (2018). https://doi.org/10.1108/IJIUS-04-2018-0010

24. Quick, D.: Aerial swarming robots to create communications networks for disaster relief. https://newatlas.com/smavnet-robot-swarm/16499/. Accessed 25 Apr 2019
25. Owano, N.: Airborne robot swarms are making complex moves (w/video). https://phys.org/news/2012-02-airborne-robot-swarms-complex-video.html. Accessed 25 Apr 2019
26. Created a "flying repeater" for the ESU TK: Army Journal "Army Gazette" (2012). https://armynews.ru/2012/10/sozdan-letayushhij-retranslyator-dlya-esu-tz/
27. The complex ESU TZ: the desired and real: Army Journal "Army Gazette" (2010). https://armynews.ru/2010/11/kompleks-esu-tz/