Service-Oriented Middleware for Multi-UAV Guided Ad Hoc Networks

Vishal Sharma*
CSED, Thapar University
Patiala, Punjab, India.
vishal_sharma2012@hotmail.com

Rajesh Kumar
SMCA, Thapar University
Patiala, Punjab, India.
rakumar@thapar.edu

Abstract

Collaboration of different ad hoc networks can extend the application of single operating ad hoc units. One of the examples of collaboratively operating network is combination of aerial and ground ad hoc networks. Both of the ad hoc networks have been implemented individually while providing varied applications in their single mode of operation. The collaboration of these networks will extend their application. For efficient collaboration and performance, a highly scalable and adaptive architectures are required that can provide robust connectivity. Such robustness can be attained by developing a service-oriented middleware that can be integrated with other network layers. In this paper, a service-oriented layered middleware is proposed that allows efficient transmission and provides longer connectivity time between the two distributed but simultaneously operating ad hoc networks. The proposed middleware is tested for its temporal dependencies in terms of service connectivity time.

Keywords: Service-oriented middleware, UAVs ad hoc networks, Guided networks, Temporal dependencies.

1 Introduction

A temporal connectivity between UAVs to achieve complex task is termed as UAVs ad hoc network. The UAVs operating in collaboration offers wide range of applications in various areas such as border surveillance, inland-security and formation of guidance units. The guidance units include multiple ad hocs that operates simultaneously in cooperation with each other. These cooperative ad hocs allows formation of distributed ad hoc networks. One of the network unit of the distributed ad hoc network, forms the guider network and another act as coordinating units based on the guider instructions obtained from the other ad hoc networks. Multi-UAV guided ad hoc network are specialized ad hoc network that aims at provision for robust map transfers that provides look ahead information.

Guided ad hoc network allows the efficient and coordinated planning amongst network nodes to achieve complex tasks. Such network can be used to resolve highly sensitive tasks in areas of military and civilian missions. Such networks can also reduce mission cost and time. Multiple nodes sharing common algorithmic approach and frameworks have greater susceptibility and adaptability in terms of network conjunctures for prediction of geographical environment. This also allows estimated evaluation of the network parameters that increases performance. UAVs operating autonomously and collaboratively have wider application range than those operating in single mode. The cooperative network formation can be carried out either by using control inputs based upon the specialized hardware specifications or can be attained using software solution that can act as interface for collaborative operations.

IT CoNvergence PRActice (INPRA), volume: 2, number: 3, pp. 24-33

*Corresponding author: Research Lab, Computer Science and Engineering Department, Thapar University, Patiala, Punjab, India-147004, Alternate Email Id: vishal.sharma@thapar.edu, Tel: +91-9780608195.

Such software solutions that provide and intermediate platform for multiple units to combine are termed as middleware. Middleware now occupies an important role in formation of collaborative systems [10]. Service based middleware can reduce the hardware cost, and allows the formation of self-configurable network. A software controlled network has wider range, and are monitored and controlled using simple network interfaces that can be handled using command interpreters with enhanced functionalities, by changing the default configurations at any time during critical missions. A well-designed software-hardware middleware can certainly increase the payload capacity and maneuverabilities of these flying objects [12]. Middleware solutions have also increased the control and guidance to varied robots that performs autonomous maneuverabilities. These software components allows matching and performance equalization of real world and embedded robot functionalities [3]. A service calibrated middleware, thus offers wide range of applications and allows configuration of network nodes for complex tasks with ease of development and deployment. These middleware also provide enhanced fault tolerance and greater network susceptibility. It can be noticed that a software solution can provide an enhanced and effective solution to collaborative network formation using hybrid nodes. It will also provide a hardware level abstraction that makes configuration and assembly of such network easy and dynamic. UAV ad hoc network formation, thus, can also be studied as software approach rather than only a network paradigm.

In this paper, a service oriented hierarchical layered middleware is proposed that allows cooperation of multi-UAV nodes to form an ad hoc network based upon the tasks as service and allows collaboration of these UAV network with other ad hoc networks. For analysis, the service middleware's data controller was analyzed for its temporal dependencies. The remaining paper is structured as follows: Related work and historical background is provided in section 2. Section 3 illustrates the proposed middleware with its functionalities and components. Section 4 illustrates the response time analysis of proposed middleware. Conclusion and future scope are presented in Section 5.

2 Related Work

Service-Oriented middleware have been used in various modes for wireless ad hoc networks. In the recent years, various service oriented approaches have been designed that aimed at providing an interface for applications requiring complex task solving abilities. Choi *et al.* have proposed an multi-layer architecture for robots operating autonomously and providing autonomous services. The architecture provides a combination of layers that operates in collaboration to each other with units having capabilities to provide facilities in form of services. The layers in the architecture varies from lower level abstraction layer to upper lying service layer. Authors aimed at providing commercialized applications through their designed architecture. The architecture uses web-integrated services to allow interaction between different layers [3].

In an another software/hardware architecture by Pastor *et al.*, authors have given a UAV mission control architecture. The designed schema provides an aerial ve hicle control system based on the several network paradigms. The architecture uses facility of local network to control the mission data for aerial vehicles. The architecture also uses an abstraction layer that facilitates the communication based on the web services [12].

Floch *et al.* have discussed the usability of service architectures for various runtime facilities. According to authors, this would certainly increase the adaptability of the system and would provide dynamism in the operations. Authors discussed the service architecture component requirement for their applicability in various mobile computing applications. The discussion stated in paper, delivers that with extensive and highly dynamic service based architecture, it is possible to formulate self configurable and adaptable systems that offer higher fault-tolerance [4].

Mohamed *et al.* have discussed a middleware based on service-oriented architecture for collaborative operability of UAVs. Authors aimed at achieving planned and coordinated mission services using a middleware as a collaborative unit. Authors have identified various aspects that are required for building architectural requirements for highly complex missions. The paper also presents various collaborative modules that are required in cooperative formation of UAVs [10].

In extension to their idea, Mohamed *et al.* have designed a service oriented middleware for UAVs. The middleware is capable in formation of cooperative network amongst UAVs. The computing facilities used are totaly service oriented. Broker architecture are used as an interface between layers of different UAVs [11].

One of the important issue in ad hoc networks is transient utilization of resources. The issue was identified by Suri *et al.* Authors taking into consideration the importance of agile computing in ad hoc networks, have experimented a service-based architecture that allows peer to peer effective transmission in MANETs like environment. It is a group oriented approach that have been experimentally tested on various network parameters for its effectiveness [19].

Tan *et al.* have identified an industry problem related to coordination. The problem is identified over data driven petri-net approach. The approach first identifies all the functionalities of the system and then generates a graphical content structure that form a network comprising of all the identified services. Although it is more of a business paradigm not a network paradigm, yet this approach can prove handy in solving multiple task problems of ad hoc networks [20].

Marconato *et al.* have analyzed a knowledge-based framework for cooperative control of UAVs. The framework is capable to provide more dynamism and allows self-configuration of UAVs, thus, making them more intelligent devices. Layered architecture and knowledge base operates in combination with each other and allows better network maneuverabilities. The approach uses service based abstraction. Round trip time evaluations have been carried to check the performance of this framework over various services [16].

Paunicka *et al.* have designed a broker architecture for autonomous aerial vehicles. This is a more of object oriented middleware that forms multi-layer to allow cooperative control for UAVs. The architecture brings together the hardware/software integration of networking modules in UAVs. The controls specifications are provided using an API that makes the model highly dynamic [14].

Lopez *et al.* worked more over the internals of aerial vehicles and targeted avionics system to form a middleware for unmanned vehicles. The middleware is capable to provide complex mission decision paradigms with efficient support from UAVs avionic system. The designed architecture provides hardware level abstraction that allows simple configuration of the system for any changes in mission [8].

In recent years, the research have been focussed on utilization of aerial vehicles resources through service middleware. But, no middleware has been identified or designed for application-oriented collaborative formation of aerial vehicles networked in ad hoc mode. Thus, the problem targeted in this paper is to design a middleware for UAVs so as to form a cooperative network with capability to interact with similar network operating simultaneously such as ground ad hoc network and then formulate a guidance system in combination with it, provided that higher level abstraction is maintained in the middleware.

3 Proposed Middleware Solution

UAV guided networks are combined distributed networks operating in collaboration with another ad hoc units. The integration of these networks is an important research task to provide seamless integration and data acquisition between different layers of the underlying networks. The network middleware allows integration of interface layer with above lying transmission layers. The middleware proposed is based on the service oriented classification, that is further divided into layered structure as shown in figure Fig. 1.

These components and features of these layers are explained below:

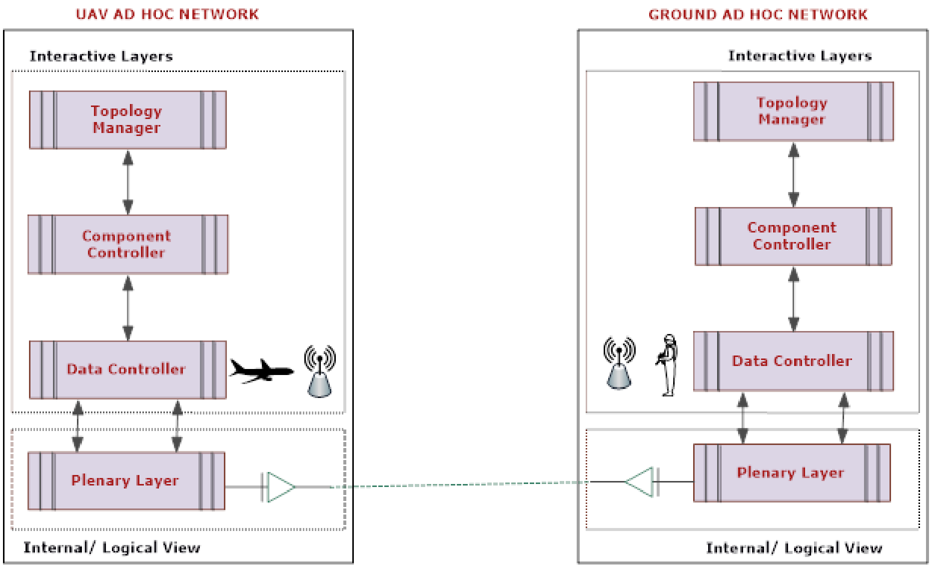

Figure 1: Layered View: Service Middleware for UAVs Ad Hoc Network

i. Topology Manager : Topology managers takes control inputs for topology organization of the network. The layers functions for network identification and maintains logs regarding location of various network nodes in both ground as well as UAV ad hoc network. The layer also integrates various path discovery algorithms that aims at exploration of network nodes and selection of suitable channel on the basis of initial configurations. Further, the layer also manages the network infrastructure that is mandatory for network formation. The topology manager copes with the underlying infrastructure and generates next localization metrics for the network nodes.

ii. Component Controller : Component Controller forms the major part of the service middleware. It acts as a control unit for the service configuration of the network. The controlling layer, is a parameterized layer that operates by generating service paradigms for the layers and then formulates the control bits that provide an abstracted control over the configurable parameters of the network. The major modules of component controller incudes parameter controller, service identifier, and resource analyzers. These modules further provide various service functionalities such as MAC controller, router configurations, security enhancers and control bit generator. The layer maintains the logs of various functional units operating over this layer. These log-maintainer also provides an interaction support for the topology manager.

iii. Data Controller : Data layer or the traffic controller for the middleware is the lower layer that finally interacts with the interface unit and allows the combination of the data units to formulate the guidance map for the guided as hoc network. The layers is multi-modular and uses control algorithms for data aggregation and segmentation. The driver units of this layer are the control algorithms that provides operational units as an input to process controller the network. The layer also controls the active traffic control and traffic generation in a specific manner so as to transmit guided computational units at better rate without any bit- latency. A coordinate analyzer computes the data receival and the localization parameters, that helps identification of generator nodes of the network. Multi-analyzers are used in this layer that provides an efficient path formation and data manipulation to form guided maps. This layer is also contains log maintainer and thus, can be utilized as estimators on their integration with various service architectures.

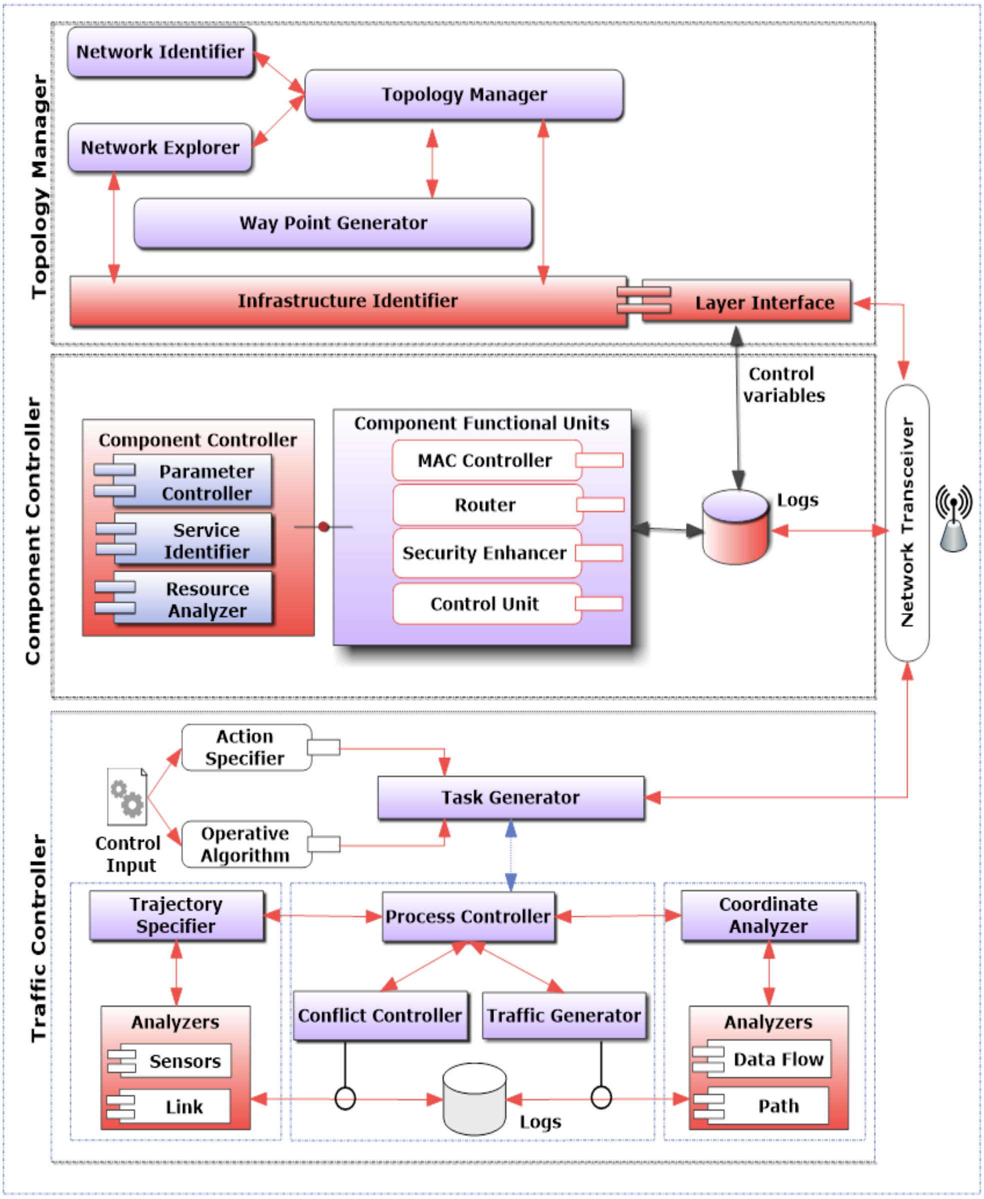

Figure 2: Service Middleware : Complete overview for source and sink

iv. Plenary Layer : The above operating layer operates as single unit in a hybrid network. However, to maintain synchronization with the simultaneously operating networks, an interactive layer is required. This layer integrates the single network operating unit with the same computational unit of the other ad hoc network. The layer is responsible for symmetrization of network bits to form a coagulated network with similar bit-representation.

The proposed middleware is capable to provide software/hardware abstraction to users. This allows easy configuration of the middleware during mission in case of any changes required due to network dynamism. The middleware is self-configurable and allows higher adaptability due to its hierarchical layered framework that senses the changes and make decision w.r.t. them. The middleware provides ease of maneuverabilities for UAVs due to collaboration, and can be easily upgraded, and integrated with existing service modules of the vehicles. The layer abstraction provided in the middleware is totally

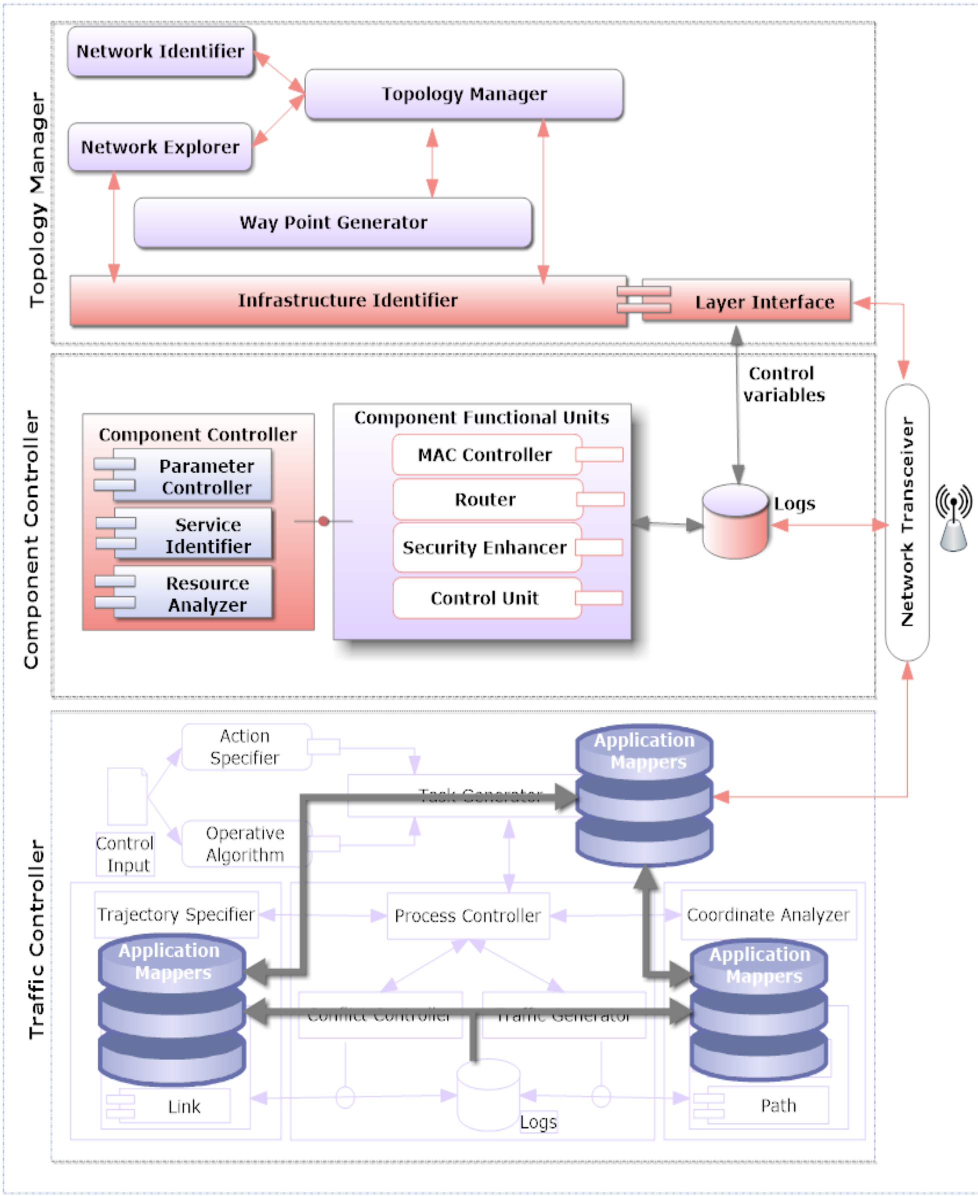

Figure 3: Service Middleware : Complete overview for relaying nodes

service oriented and do not require any complex data transfers for control components.

3.1 Inter-layer Communication over Service Middleware

A middleware comprising of several service layer architecture, requires a versatile inter-layer communication support that can be used in both the types of ad hoc networks as shown in Fig. 3. Each middleware layer is provided with an interface and log maintainer that interacts with each other to provide shared access to network memory for inter-process communication. These layers interact directly with the transceiver unit of the network and allows inter-network data transfers. The data layer operates using log-base as its base model. For the collaborative transmission, the one selected as traffic generator, allows direct usage of data controller and for others, acting as relaying nodes in the network, underlying data controller components are not directly used, rather a multi-log based approach is facilitated to form a hybrid data layer that share similar data between all the relaying nodes. These multi-logs are termed as application mappers.

The inter-process communication is selected on the basis of network architecture which controls the service midleware. Service middleware allows multiple UAVs to have similar data oriented software solutions despite of their different manufacturing variations. This causes UAVs with different features and configurations to unite and form a temporary ad hoc unit that operates to achieve complex tasks based on the operational algorithms. Thus, hybrid node interaction and situational localization is possible to attain using this service-based middleware.

4 Time Dependency of Service Middleware

Analysis of a service middleware is performed for its temporal dependencies as response time for each unit is critical in formation of guidance maps. The latency in any form can prove fatal for the network. This response time reduces if the connectivity time between the ground ad hoc and the aerial ad hoc is increases, as it would allow more efficient data transfers with better ability to confirm data checks. Greater the connectivity time, more robust is the network. For this, the service middleware's data controllers performance was analyzed over connectivity time w.r.t number of nodes.

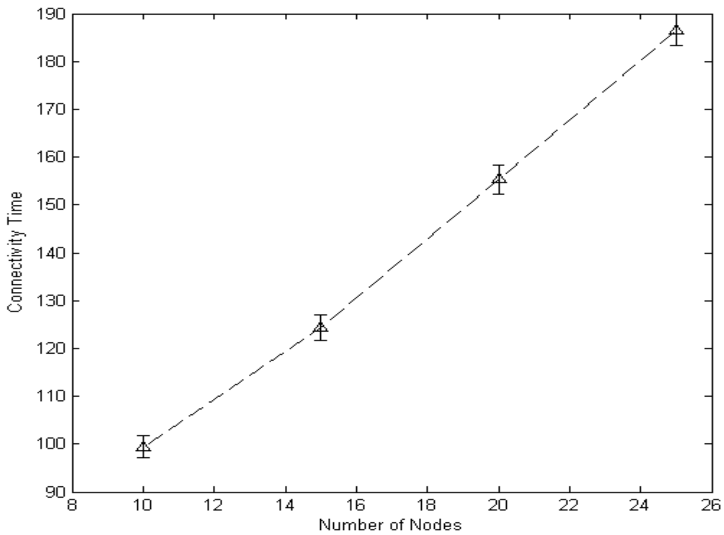

Figure 4: Service connectivity time w.r.t number of nodes

Fig. 4, shows that service middleware offered more connectivity time with increase in number of nodes. This is due to the fact that more UAVs provide sufficient time to recover from network faults and halts that hinders the data transmission.

The confidence range of service middleware w.r.t. logarithmic increase in connectivity time also shows an increase denoting that service middleware is capable to handle large number of nodes. Thus, proving it to be highly scalable. The results showing increase in confidentiality of the middleware is shown in Fig. 5.

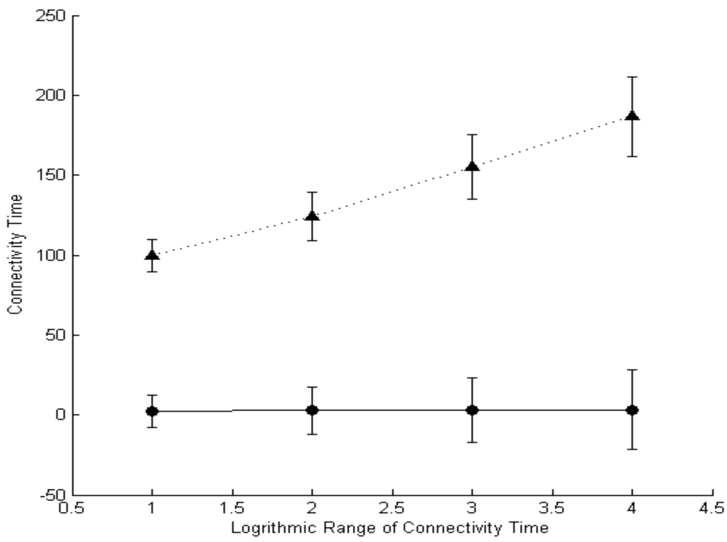

Figure 5: Confidentiality plot logarithmic connectivity

5 Conclusion

In this paper, a service-oriented hierarchical middleware is proposed that allows formation of cooperative ad hoc using unmanned aerial vehicles that are capable enough to form a guidance unit. The middleware is based on multi-layered approach that used layer to layer abstraction based on service interaction over interfaces. The temporal dependency in form of service configuration time is carried that shows the increase in confidentiality level of the middleware functionality.

The proposed middleware is capable to provide self-configurable, adaptive and efficient connectivity between the aerial and ground ad hoc network. Also, the layered architecture allows its easy integration with existing service models for data transmission with lower latency and higher accuracy.

5.1 Future Work

In future, the service oriented middleware can be extended to formulate the complete service architecture for aerial guided ad hoc networks. Also, its analysis can be further carried out by integrating it with existing network frameworks.

References

[1] A. Agalgaonkar, S. Kulkarni, and S. Khaparde. Multi-attribute decision making approach for strategic planning of dgs. In *Proc. of the 2005 IEEE Power Engineering Society General Meeting (PES'05), San Francisco, USA*, pages 2985–2990. IEEE, June 2005.

[2] J. Al-Jaroodi and N. Mohamed. Service-oriented middleware: A survey. *Journal of Network and Computer Applications*, 35(1):211–220, January 2012.

[3] J. Choi, Y. Cho, J. Choi, and J. Choi. A layered middleware architecture for automated robot services. *International Journal of Distributed Sensor Networks*, 2014(2014):1–10, May 2014.

[4] J. Floch, S. Hallsteinsen, E. Stav, F. Eliassen, K. Lund, and E. Gjorven. Using architecture models for runtime adaptability. *IEEE Software*, 23(2):62–70, March-April 2006.

[5] E. W. Frew and T. X. Brown. Networking issues for small unmanned aircraft systems. *Journal of Intelligent and Robotic Systems*, 54(1-3):21–37, March 2009.

[6] K. Kim. A model-driven workflow fragmentation framework for collaborative workflow architectures and systems. *Journal of Network and Computer Applications*, 35(1):97–110, January 2012.

[7] J. Kramer and J. Magee. Self-managed systems: an architectural challenge. In *Proc. of the 2007 Future of Software Engineering (FOSE'07), Minneapolis, USA*, pages 259–268. IEEE, May 2007.

[8] J. López, P. Royo, E. Pastor, C. Barrado, and E. Santamaria. A middleware architecture for unmanned aircraft avionics. In *Proc. of the 24th ACM/IFIP/USENIX international conference on Middleware companion Article (MC'07), Newport Beach, USA*, pages 1–1. ACM, November 2007.

[9] J. P. Loyall. Emerging trends in adaptive middleware and its application to distributed real-time embedded systems. In *Proc. of the 3rd International conference on Embedded Software (EMSOFT'03), Philadelphia, USA, LNCS*, volume 2855, pages 20–34. Springer-Verlag, October 2003.

[10] N. Mohamed, J. Al-Jaroodi, I. Jawhar, and S. Lazarova-Molnar. Middleware requirements for collaborative unmanned aerial vehicles. In *Proc. of the 2013 International Conference on Unmanned Aircraft Systems (ICUAS'13), Atlanta, USA*, pages 1051–1060. IEEE, May 2013.

[11] N. Mohamed, J. Al-Jaroodi, I. Jawhar, and S. Lazarova-Molnar. Data-driven service composition in enterprise soa solutions: a petri net approach. *Journal of Intelligent & Robotic Systems*, 74(1-2):309–321, April 2014.

[12] E. Pastor, J. Lopez, and P. Royo. A hardware/software architecture for uav payload and mission control. In *Proc. of the 25th Digital Avionics Systems Conference (DASC'06), Portland, Oregon*, pages 1–8. IEEE, October 2006.

[13] D. J. L. Paunicka, B. R. Mendel, and D. D. E. Corman. The ocp-an open middleware solution for embedded systems. In *Proc. of the 2001 American Control Conference (ACC'01), Arlington, USA*, pages 3445–3450. IEEE, June 2001.

[14] J. L. Paunicka, D. E. Corman, and B. R. Mendel. A corba-based middleware solution for uavs. In *Proc. of the 4th IEEE International Symposium on Object-Oriented Real-Time Distributed Computing (ISORC'01), Magdeburg, Germany*, pages 206–267. IEEE, May 2001.

[15] R. Perrey and M. Lycett. Service-oriented architecture. In *Proc. of the 2003 Symposium on Applications and the Internet Workshops (SAINT'03), Orlando, Florida*, pages 116–119. IEEE, January 2003.

[16] D. Rodrigues, J. C. Estrella, M. Vieira, M. Corrêa, J. ao Batista Camargo Junior, K. R. C. Branco, and O. T. Jr. Unmanned aerial vehicles & service-oriented architecture: Larissa and knowledge based framework's first study. In *Proc. of The I Brazilian Conference on Critical Embedded Systems (CBSEC'11), São Carlos, Brazil*, pages 130–130, May 2011.

[17] E. Santamaria, P. Royo, J. Lopez, C. Barrado, E. Pastor, and X. Prats. Increasing uav capabilities through autopilot and flight plan abstraction. In *Proc. of the 26th Digital Avionics Systems Conference (DASC'07), Texas, USA*, pages 5.B.5–1–5.B.5–10. IEEE, October 2007.

[18] N. Suri. Dynamic service-oriented architectures for tactical edge networks. In *Proc. of the 4th Workshop on Emerging Web Services Technology (WEWST'09), Fairfax, Virginia, USA*, pages 135–147. ACM, October 2003.

[19] N. Suri, M. Marcon, R. Quitadamo, M. Rebeschini1, M. Arguedas, S. Stabellini, M. Tortonesi, and C. Stefanelli. An adaptive and efficient peer-to-peer service-oriented architecture for manet environments with agile computing. In *Proc. of the 2008 IEEE Network Operations and Management Symposium Workshops (NOMS'08), Salvador da Bahia, Brazil*, pages 364–371. IEEE, April 2008.

[20] W. Tan, Y. Fan, M. Zhou, and Z. Tian. Data-driven service composition in enterprise soa solutions: a petri net approach. *IEEE Transactions on Automation Science and Engineering*, 7(3):686–694, July 2010.

Author Biography

Vishal Sharma is currently a research scholar in Thapar University, Patiala. He obtained his B.Tech from Punjab Technical University. He has more than 25 research papers to his credit in various international journals and conferences. He is member of IEEE/ACM and Chair for Student Chapter-Patiala. His area of research and interest are Wireless Ad hoc Networks, Soft Computing, Estimation Theory, and Artificial Intelligence.

Rajesh Kumar is currently an Associate Professor and Head, SMCA in Thapar University, Patiala. He Obtained his M.Sc., M. Phil. and Ph. D. degree from IIT Roorkee. He has more than 16 years of UG & PG teaching and research experience. He has more than 70 research papers to his credit in various international and national Journals and conferences. He is member of various professional bodies/societies of repute. His area of research and interest includes Mathematical Modeling, Wireless Networks, Software Engineering, and Pattern Recognition.