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Article *in* International Journal of Innovative Research in Computer and Communication Engineering · August 2019

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ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 5, May 2014

Aircraft Ad-hoc Network (AANET)

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Abstract: Aircraft ad hoc networks are defined as self organizing networks where airplane works as node. Ad-hoc network is dynamic network which can be created anywhere with just two basic nodes and does not require any centralize infrastructure. Each node has a certain range of communication in which it can transmit or receive data. We are proposing AANET (Aircraft Ad-hoc Network). In these networks, aircraft is envisioned to participate as a self-aware node and communicates with ground infrastructure and other aircrafts. Thus, these networks show different features with typical ad hoc networks in that information becomes available through in-aircraft, aircraft-to-ground and aircraft-to-aircraft, aircraft-to-ship communications also sent the signal of army radar and a GPS is used for navigation. With help of these networks, traffic between aircrafts can be distributed and is regarded to have improved communication, reliability, security as well as scalability. Based on this property, the need of aircraft ad hoc networks increases. The enhancements in information delivery and availability from in-aircraft, aircraft-to-ground and aircraft-to-ship, aircraft-to-aircraft communications in the AANET can improve areas such as flight safety, schedule predictability, maintenance and operational efficiencies, passenger amenities.

Key words: Ad-hoc Network, AANET, Vanet, Manet, Craft.

I. INTRODUCTION

Air ad hoc networks (AANETs) can provide scalable and cost-effective solutions for applications such as traffic safety, dynamic route planning, and context-aware advertisement using long-range wireless communication. Data is transmitted in the form of small packets. If it need to communicate to a other node which is outside is range, it may do so by sending the data to a node which is within a cover range. That node will transmit to the next and so on till it reaches to its designated destination.

In the pure mobile ad hoc networks (MANET) [1], participating nodes are willing to construct self-organizing networks without any help of centralized point whenever it is needed. Thus, a node should collaborate with other nodes to build networks autonomously in a distributed way. One of the most outstanding features in this kind of networks is mobility support. Thus, each node is allowed to move anywhere and anytime freely in this network. As compared to existing network technology, the need of mobile ad hoc networks increases rapidly because many applications are demanding it. Example of communication environments for mobile ad hoc networks includes communication in tactical area as well as disaster area where infrastructure network is not available or rapid network deployment is required. Moreover, both telecommunication and teleconference are good examples for application in these environments.

Recently, AANET [2] (Aircraft Ad Hoc Networks) have been proposed. In which we are moving from VANET to AANET. In these networks, aircraft is envisioned to participate as a self-aware node and communicates with ground infrastructure and other aircrafts. Thus, these networks show different features with typical ad hoc networks in that information becomes available through in-aircraft, aircraft-to-ground and aircraft-to-aircraft, aircraft-to-ship communications and also sent the signal to army radar. With help of these networks, traffic between aircrafts can be distributed and is regarded to have improved reliability as well as scalability. Based on this property, the need of aircraft ad hoc networks increases due to an unprecedented increase in air traffic, fuel costs and environmental pollution.

One of the most prominent design problems is communication. In this paper, Aircraft Ad-Hoc Network (AANET),which is basically ad hoc network. The differences between Mobile Ad-hoc Network (MANET), Vehicular Ad-hoc Network (VANET) and AANET are outlined, and the most important AANET design challenges are introduced. In addition to the existing solutions, the open research issues are also discussed.

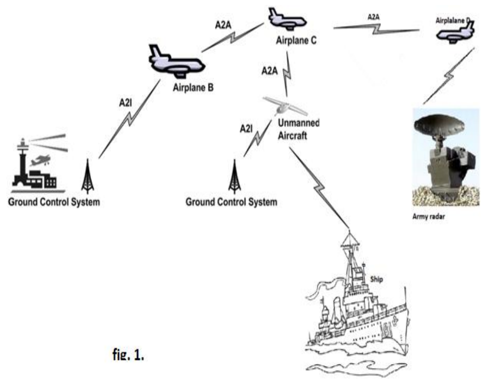

Fig: 1

II. AANET APPLICATION SCENARIOS

In this section, different AANET application scenarios are discussed.

2.1 Extending the scalability of multi-crafts operations. If a multi-craft communication network is established fully based on an infrastructure, such as a satellite or a ground base, the operation area is limited to the communication coverage of the infrastructure. If a craft cannot

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 5, May 2014

ISSN (Online) : 2278-1021
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communicate with the infrastructure, it cannot operate. On the other hand, AANET is based on the craft-to-craft data links instead of craft-to-infrastructure data links, and it can extend the coverage of the operation. Even if a AANET node cannot establish a communication link with the infrastructure, it can still operate by communicating through the other crafts. This scenario is illustrated in

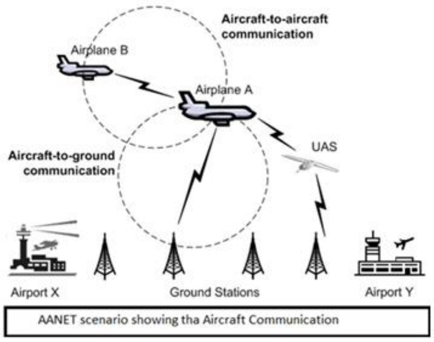

Fig 2.

There are several AANET designs developed for extending the scalability of multi-craft applications. In [3], a AANET design was proposed for the range extension of multi- craft systems. It was stated that forming a link chain of crafts by utilizing multi-hop communication can extend the operation area. It should be noticed that the terrain also affects the communication coverage of the infrastructure. There may be some obstacles on the terrain, such as mountains, walls or buildings, and these obstacles may block the signals of the infrastructures. Especially in urban areas, buildings and constructions block the radio signals between the ground base and crafts. AANET can also help to operate behind the obstacles, and it can extend the scalability of multi-craft applications [4].

2.2 Reliable multi-craft communication

In most of the cases, multi-craft systems operate in a highly dynamic environment. The conditions at the beginning of a mission may change during the operation. If there is no opportunity to establish an ad hoc network, all crafts must be connected to an infrastructure, as illustrated in Fig. 2a. However, during the operation, because of the weather condition changes, some of the crafts may be disconnected. If the multi-craft system can support AANET architecture, it can maintain the connectivity through the other crafts, as it is shown in Fig. 2b. This connectivity feature enhances the reliability of the multi-craft systems [5].

fig. 2 a

Fig:2a

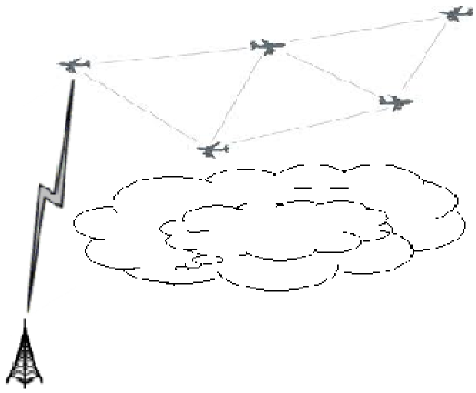

Fig2.b

III. AANET DESIGN CHARACTERISTICS

Before discussing the characteristics of AANETs, we provide a formal definition of AANET and a brief discussion about the definition to understand AANET clearly. AANET can be defined as a new form of MANET in which the nodes are planes. According to this definition, single craft systems cannot form a AANET, which is valid only for multi-craft systems. The plane communication must be realized by the help of an ad hoc network between crafts or planes. Therefore, if the communication between crafts fully relies on craft-to-infrastructure links, it cannot be classified as a AANET. In the literature, AANET related researches are studied under different names. For example, aerial robot team is a collaborative and autonomous multi-UAV system, and generally, its network architecture is ad hoc [6].

Another AANET related topic is aerial sensor network [7–9]. Aerial sensor network is a very specialized mobile sensor and actor network so that the nodes are crafts. It moves around the environment, senses with the sensors on the crafts and relays the collected data to the ground base. In addition, it can act with its actors on the planes to realize its mission. It is a perception issue to name the problem as aircraft ad hoc network or aerial sensor network. The basic design challenges of a traditional sensor network are energy consumption and node density [10], and none of them is related with multi-craft systems. Generally, crafts have enough energy to support its communication hardware, and node density of a multi-craft system is very low when it is compared to traditional sensor networks. Under the light of these discussions, it is better to classify the multi-plane communication system based on craft-to-craft links as a specialized ad hoc network, instead of a specialized sensor network. However, AANET term immediately reminds that it is a specialized form of MANET and VANET. Therefore, we prefer calling it as Aircraft Ad-Hoc Network, AANET.

3.1. Differences between AANET and the existing ad-hoc networks

Wireless ad hoc networks are classified according to their utilization, deployment, communication and mission objectives. By definition, AANET is a form of MANET, and there are many common design considerations for

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

MANET and AANET. In addition to this, AANET can also be classified as a subset of VANET, which is also a subgroup of MANET. This relationship is illustrated in Fig. 3. As an emerging research area, AANET shares common characteristics with these networks, and it also has several unique design challenges. In this subsection, the differences between AANET and the existing wireless ad hoc networks are explained in a detailed manner.

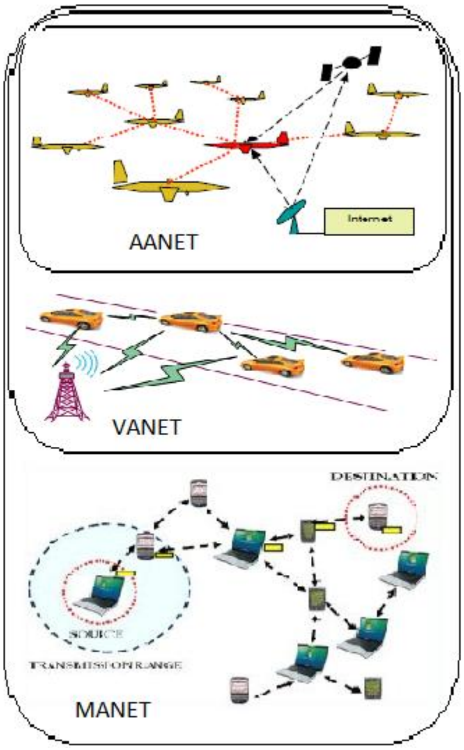

Fig. 3. MANET, VANET and AANET.

3.1.1. Node mobility

Node mobility related issues are the most notable difference between AANET and the other ad hoc networks. MANET node movement is relatively slow when it is compared to VANET. In AANET, the node's mobility degree is much higher than in the VANET and MANET. According to [5], a craft has a speed of 30–460 km/h, and this situation results in several challenging communication design problems [11].

3.1.2. Mobility model

While MANET nodes move on a certain terrain, VANET nodes move on the highways, and AANET nodes fly in the sky. MANETs generally implement the random waypoint mobility model [12], in which the direction and the speed of the nodes are chosen randomly. VANET nodes are restricted to move on highways or roads. Therefore, VANET mobility models are highly predictable. In some multi-craft applications, global path plans are preferred. In this case, crafts move on a predetermined path, and the mobility model is regular. In autonomous multi-craft systems, the flight plan is not predetermined. Even if a multi-crafts system uses predefined flight plans, because of the environmental changes or mission updates, the flight plan may be recalculated. In addition to the flight plan changes, the fast and sharp crafts movements and different plane formations directly affect the mobility model of multi-craft systems. In order to address this issue, AANET mobility models are proposed.

3.1.3. Node density

Node density can be defined as the average number of nodes in a unit area. AANET nodes are generally scattered in the sky, and the distance between Crafts can be several kilometers even for small multi- Craft systems [13]. As a result of this, AANET node density is much lower than in the MANET and VANET.

3.1.4. Topology change

Depending on the higher mobility degree, AANET topology also changes more frequently than MANET and VANET topology. In addition to the mobility of AANET nodes, Craft platform failures also affect the network topology. When a Craft fails, the links that the Craft has been involved in also fail, and it results in a topology update. As in the Craft failures, Craft injections also conclude a topology update. Another factor that affects the AANET topology is the link outages. Because of the Craft movements and variations of AANET node distances, link quality changes very rapidly, and it also causes link outages and topology changes [14].

3.1.5. Radio propagation model

Differences between AANET and the other ad hoc net work operating environments affect the radio propagation characteristics. MANET and VANET nodes are remarkably close to the ground, and in many cases, there is no line-of-sight between the sender and the receiver. Therefore, radio signals are mostly affected by the geographical structure of the terrain. However, AANET nodes can be far away from the ground and in most of the cases, there is a line-of-sight between Crafts.

3.1.6. Power consumption and network lifetime

Network lifetime is a key design issue for MANETs, which especially consist of battery-powered computing devices. Developing energy efficient communication protocols is the goal of efforts to increase the network lifetime. Especially, while the battery-powered computing devices are getting smaller in MANETs, system developers have to pay more attention to the energy efficient communication protocols to prolong the lifetime of the network. However, AANET communication hardware is powered by the energy source of the Craft. This means AANET communication hardware has no practical power resource problem as in MANET.

3.2. AANET design considerations

3.2.1. Adaptability

There are several AANET parameters that can change during the operation of a multi-Craft system. AANET nodes are highly mobile and always change their location. Because of the operational requirements, the routes of the Crafts may be different, and the distance between Crafts cannot be constant. Another issue that must be considered is the Craft failures. Consequent to a technical problem or an attack against multi-Craft system, some of the Crafts may fail during the operation. While Craft failures decrease the number of Crafts, Crafts injections may be required to maintain the multi-Craft system operation. Craft failures and Craft injections change the AANET parameters. Environmental conditions can also affect AANET. If the weather changes unexpectedly, AANET data links may not survive. AANET should be designed so that it should be able to continue to operate in a highly dynamic environment. The mission may also be updated during the multi-Crafts system operation. Additional data or new information about the mission may require a flight plan update.

3.2.2. Scalability

Collaborative work of Crafts can improve the performance of the system in comparison to a single-Craft system. In fact, this is the main motivation to use multi-Craft based systems. In many applications, the performance enhancement is closely related with the number of Crafts. For example, the higher number of Crafts can complete a search and rescue operation faster [15]. AANET protocols and algorithms should be designed so that any number of Crafts can operate together with minimal performance degradation.

3.2.3. Latency

Latency is one of the most important design issues for all types of networks, and AANET is not an exception. AANET latency requirement is fully dependent on the application. Especially for real-time AANET applications, such as military monitoring, the data packets must be delivered within a certain delay bound. Another low latency requirement is valid for collision avoidance of multiple Crafts [29,16].

3.2.4. Bandwidth requirement

In most of the AANET applications, the aim is to collect data from the environment and to relay the collected data to a ground base [17]. For example, in surveillance, monitoring or rescue operations; the image or video of the target area must be relayed from the Craft to the command control center with a very strict delay bound, and it requires high bandwidth. In addition, by the help of the technological advancements on sensor technologies, it is possible to collect data with very high resolution, and this makes the bandwidth requirement much higher. The collaboration and coordination of multiple Crafts also need additional bandwidth resource. On the other hand, there are many constraints for the usage of available bandwidth such as: capacity of the communication channel, speed of Crafts, error-prone structure of the wireless links, lack of security with broadcast communication. An AANET protocol must satisfy the bandwidth capacity requirement so that it can relay very high resolution real-time image or video under several constraints.

IV. COMMUNICATION PROTOCOLS FOR AANETS

In this section, the AANET communication protocols and the open research issues are presented.

4.1. Physical layer

The existing AANET protocols proposed for the physical layer, medium access control (MAC) layer, network layer, transport layer, and their cross-layer interactions. The physical layer deals with the basic signal transmission technologies, such as modulation or signal coding. Various data bit sequences can be represented with different waveforms by varying the frequency, amplitude and phase of a signal. Overall, in the physical layer, the data bits are modulated to sinusoidal waveforms and transmitted into the air by utilizing an antenna. To develop robust and sustainable data communication architectures for AANET, the physical layer conditions have to be well understood and well-defined. Recently, Craft-to-Craft and Craft-to-ground communication scenarios have been broadly studied in both simulation and real-time environments.

4.1.2. AANET antenna structure

The antenna structure is one of the most crucial factors for an efficient AANET communication architecture. The distance between crafts is longer than typical node distance of MANETs and VANETs, and it directly affects the AANET antenna structure.

Antenna type is another factor that affects the AANET performance. There are two types of antennas deployed for AANET applications: directional and omnidirectional. While omnidirectional antennas radiate the power in all directions, directed antenna can send the signal through a desired direction. In highly mobile environments, as in AANET, the node locations change frequently and omnidirectional antennas have a natural advantage to transmit and receive signals. In omnidirectional antennas, node location information is not needed. However, directional antennas also have several advantages when compared to omni-directional antennas. Firstly, the transmission range of a directed antenna is longer than the transmission range of an omni-directional antenna [18]. Directional antenna based systems can handle communication range and spatial reuse problem for AANETs, at the same time. While it can increase communication range, it does not limit spatial reuse [19]. Depending on the higher spatial reusability, the capacity of a network with directed antenna is higher than the capacity of a network with omni directional antenna.

Open research issues The characteristics of the physical layer affect the design of the other layers and the overall AANET performance directly. The performance analysis of the existing physical layer protocols and developing new physical layer designs for 3D are largely unexplored issues for AANETs

4.2. MAC layer

Although MANET, VANET and AANET have different challenges and characteristics, they have also several common design considerations. Basically, AANET is a special subset of MANET and VANET. In this sense, the first AANET examples use IEEE 802.11 with omni directional antennas [12,20], which is one of the most commonly used MAC layers for MANETs.

4.2.1. Challenges of AANET MAC layer

High mobility is one of the most distinctive properties of AANET, and it presents new problems for the MAC layer.

Because of the high mobility and the varying distances between nodes, link quality fluctuations take place in AANETs frequently. Link quality changes and link outages directly affect AANET MAC designs. Packet latency is another design problem for AANET MAC layer design. Especially for real time applications, packet latency must be bounded and it imposes new challenges

Open research issues Providing a robust AANET MAC layer necessitates to address and overcome some unique challenging tasks such as link quality variations caused by high mobility, and longer distance between nodes.

4.3. Network layer

One of the first flight experiments with AANET architecture is performed in SRI International [21]. In this research, Topology Broadcast based on Reverse-Path Forwarding(TBRPF) [22], which is basically a proactive protocol, is used as the network layer to minimize the overhead. In [23], Brown et al. developed another AANET test bed with Dynamic Source Routing (DSR) [24] protocol. The main motivation to choose DSR is its reactive structure. The source tries to find a path to a destination, only if it has data to send. There are also some other AANET studies that use DSR. Khare et al. stated that DSR is more appropriate than proactive methods for AANETs, where the nodes are highly mobile, and the topology is unstable [25].Because of the high mobility of the AANET nodes, maintaining a routing table, as in proactive methods, is not optimal. However, repetitive path finding before each packet delivery, as in reactive routing, can also be exhaustive. A routing strategy only based on the location information of the nodes can satisfy the requirements of AANET. In [26], proactive, reactive and position-based routing solutions are compared for AANETs. It was shown that Greedy Perimeter Stateless Routing (GPSR) [27], which is a position-based protocol, outperformed proactive and reactive routing solutions. Shirani et al. developed a simulation framework to study the position-based routing protocols for AANETs [28]. It was stated that greedy geographic forwarding based routing protocols can be used for densely deployed AANETs. However, the reliability can be a serious problem in case of sparse deployments. A combination of other methods, like face routing, should be used for the applications that require 100% reliability.

Open research issues Routing is one of the most challenging issues for AANETs. Because of the unique AANET challenges, the existing MANET routing solutions cannot satisfy all the AANET requirements. The existing AANET routing solutions are presented in Peer-to-peer communication is essential for collaborative coordination and collision avoidance of multi-craft systems. However, it is also possible to use AANET to collect information from the environment as in wireless sensor networks, which generate different traffic pattern. All the data are routed to a limited set of crafts that are directly connected to an infrastructure. Developing new routing algorithms that can support peer-to peer communication and converge cast traffic is still an open issue. Data centric routing is a promising approach for AANETs. By the help of the publish subscribe architecture of data centric algorithms, it can be possible to produce multi-craft systems that can support different applications. To the best of our knowledge, data centric AANET algorithms are totally unexplored.

4.4. Transport layer

The success of AANET designs is closely related to the reliability of the communication architecture, and setting up a reliable transport mechanism is essential, especially in a highly dynamic environment.

The main responsibilities of an AANET transport protocol are as follows:

Reliability: Reliability has always been the primary responsibility of transport protocols in communication networks. Messages should be reliably delivered to the destination node to ensure proper functionalities. Data may be simple text/binary in which 100% reliability is required, or it may be multimedia streams in which low reliability is acceptable. AANET transport protocol should support different reliability levels for different AANET applications.

Congestion control: The typical consequences of a congested network are the decrease in packet delivery ratio and the increase in latency. If a AANET is congested, collaboration and collision avoidance between Crafts cannot be performed properly. A congestion control mechanism is necessary to achieve an efficient and reliable AANET design.

Flow control: Because of a fast sender or multiple senders, the receiver may be overloaded. Flow control can be a serious problem especially for heterogeneous multi-craft systems

Open research issues Contrary to the wired networks and MANETs, AANETs are characterized by highly mobile nodes and wireless communication links with high bit error rates. They have frequent link outages according to the positions of Crafts and ground stations. Reliability is a critical issue for AANET transport layers.

V. CONCLUSION

Communication is one of the most challenging design issues for multi-Crafts systems. In this paper, The AANET promises applications that can significantly benefit next-generation air transportation systems. Our security analysis focused on information assets that could impact airplane operation, airplane maintenance and air traffic control and provided AANET design considerations are also investigated as adaptability, scalability, latency, and bandwidth.

We also discuss the differences between AANET and other ad hoc network types in terms of mobility, node density, topology change, radio propagation model, power consumption, computational power and localization. For the further works, a new routing protocol mentioned in discussion section will be studied and developed. Also, other issues for realistic mobility model such as avoiding crash remains.

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

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