ISSN 2348-1196 (print)
International Journal of Computer Science and Information Technology Research ISSN 2348-120X (online)
Vol. 4, Issue 2, pp: (99-113), Month: April - June 2016, Available at: www.researchpublish.com

Robust and Auto-Configurable Network Service Framework for Airborne Network

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Abstract: **The airborne network (AN) is envisioned as an IP-based hierarchical network with heterogeneous nodes. It is highly dynamic in nature and has bandwidth constraints. There is a need for new Airborne Network technologies needed to provide reliable network operations for terrestrial networks. This seminar topic identifies challenges in designing and evaluating AN technologies. This topic introduces a realistic wireless testing and performance evaluation framework for AN testing and evaluation. There are set of cases to illustrate how the framework can be used to evaluate new architecture and protocols in AN environments. In this topic I have only one case and evaluated the results.**

Keywords: **Net-centric, Network Capability, IANetserv, RFNEST, JANSS.**

1. INTRODUCTION

Net-centric warfare demands effective linking or networking of various network assets that are geographically or hierarchically dispersed, operating with various protocols and communication links and waveforms (i.e., RF, Optical, and SATCOM), and forming different topologies. The networking of knowledgeable network assets further facilitates information sharing to ensure shared awareness and mission success. The former Air Force Chief of Staff, General John Jumper, has initialized the effort of Airborne Networks (ANs) with seamless integration of Internet based network in-the-sky into the Global Information Grid (GIG). As illustrated in Figure 1, ANs will provide such an enabling networking infrastructure, which consists of IP-based airborne nodes that provide interconnectivity among terrestrial network, space networks, maritime networks, and various other types of networks through backbone in-the-sky as part of the GIG. One of the main goals of ANs is to reduce sensor-to-shooter timeline by combining data from disparate sensors, air platforms, and ground stations. The future AN technologies will be capable of supporting diverse heterogeneous networks (subnets) operating with various protocols and communication links, and forming different topologies. The constellation of ISR, C2 and targeting networks are examples of subnet technologies.

Current military networks provide only their own mission specific implementations, operate at different frequency bands, use different waveforms (i.e., Link 16, TTNT, CDL, MADL/SADL, Optical/Laser, and SATCOM, etc), and provide limited interoperability and autonomous routing capability. In order to enable the vision of networked information exchange across these networks, an autonomous end-to-end networking needs to be developed. Towards this goal, significant research efforts have been made on designing efficient networking technologies to fulfill the stringent requirements of ANs, such as high network dynamics, bandwidth efficiency, security, and robustness. In addition, the process of testing various AN technologies in a realistic way remains to be a big challenge faced by all AN researchers. In other words, once the necessary networking technologies are identified and developed, they need to be thoroughly tested and evaluated to justify their feasibility performance. Simulations are typically simplistic and cannot fully capture physical channel effects in AN environments. On the other hand, static test beds in lab environment cannot represent high network dynamics, whereas field tests with real hardware are costly to execute.

Figure 1: Airborne Network Architecture

This topic introduces a realistic wireless network emulation capability to test and evaluate innovative technologies and modifications towards existing protocols under realistic AN scenarios. Diverse use cases are presented to show how one can use high fidelity wireless channel emulator to reduce the cost and increase the speed of design, prototyping, and deployment of AN technologies.

1.1 Definition of Airborne Network:

The Airborne Network is defined to be an infrastructure that provides communication transport services through at least one node that is on a platform capable of flight. This can best be visualized in the context of the operating domains served by the Global Information Grid (GIG). The Transformational Communications Satellite System (TSAT) network will provide space connectivity and the GIG-Bandwidth Expansion (GIG-BE) network together with networks such as those provided under the Combat Information Transport System and Theater Deployable Communications will provide surface connectivity. Airborne connectivity within the GIG will be provided by the Airborne Network. The Airborne Network will connect to both the space and surface networks, making it an integral part of the communications fabric of the GIG.

1.2(a) Operational Concept Description for the Airborne Network:

Network-centric operations and network-centric warfare (NCW) refers to an information superiority-enabled concept of operations that generates increased combat power and air mobility by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self synchronization. In essence, NCW translates information superiority into combat power by effectively linking knowledgeable entities in the battle space. [Source: Network Centric Warfare, Alberts, Gartska and Stein, 1999]

The Department of Defense (DoD) Joint Vision (JV) 2020 projects to a future period of United States dominance across the full spectrum of military operations. The military capabilities necessary to realize this vision depend upon achieving Information and Decision Superiority through the implementation of an internet-like, assured Global Information Grid (GIG). Within the AF, achieving Information and Decision Superiority depends upon extending the capabilities of the GIG into the airborne and space environments. When fully realized, this AF vision will enable interoperable network-centric operations between Joint Service, Allied, and Coalition forces. [Source: Airborne Network Prioritization Plan]

To realize the AF vision, the extension of the GIG in the airborne domain – the Airborne Network, must be easy to use, configure, and maintain and must provide:

- Ubiquitous and assured network access to all Air Force platforms
- GIG core services whose integrity is assured
- Quality appropriate to the commander's intent and rules of engagement (ROE)
- Rapid response to mission growth, emerging events and changing mission priorities
- End-to-end interoperation with joint services, coalition, and non-DoD partners and legacy systems in all physical network domains (sub-surface, surface, airborne and space)

1.2(b) Airborne Network Communications Capabilities:

The Airborne Network that can provide the capabilities listed in table 1-1 will be a communications utility that provides an adaptable set of communications capabilities that can be matched to the particular mission, platforms, and communications transport needs. Communications capabilities can be expressed in terms of the connectivity that can be established, the services that can be supported over the network connections, and the operations that are required for the user to establish, maintain, and access the network connections. Table 1-1 identifies an objective set of communications capabilities for the Airborne Network. All of these capabilities would not necessarily be needed for every instantiation of the Airborne Network, but will be necessary to support all missions, operations, and platforms.

Table 1: Summary of Airborne Network Objective Capabilities

Network Capability & Attributes	Airborne Network Objective Capabilities
Connectivity	
Coverage Geographic span of links directly interfacing to a subject node	• Beyond Line of Sight (BLOS) extending Globally (enabling access to anywhere from anywhere)
Diversity of links Total number and types of links that can be used to "connect" to the subject node	• Number of links (system and media) matched to the mission matched to the environment (to enable guaranteed access) • Type of links extend across the spectrum of radio frequencies including infrared and optical
Throughput Total average throughput of all links directly interfacing to the subject node	• Throughput matched to the mission and automatically adaptable to accommodate unplanned or transient conditions • Dynamically reconfigurable to optimize performance, cost, and mission effectiveness
Type of connection Nature of connections that can be established between the subject nodes and directly connected nodes	• Flexible connections able to forward Globally
Network interface Networks that can be directly interfaced from the subject node (e.g., DISN (NIPRNET, SIPRNET, JWICS), Transformational Communications, TDL Networks, CDL Networks)	• Interface to AN subnet and backbone links, as well as, legacy (i.e., TDL or CDL), coalition and GIG component networks operating any version network protocol (i.e., IPv6 or IPv4), as needed
Services	
Real-time data Any data flows that must be sent in real time (i.e., low latency) with assured delivery (e.g., AMTI or GMTI tracks, munition terminal stage updates, RPV control, TCT&ISR tipoffs, NBC alert)	• Multiple simultaneous multilevel precedence and preemption (MLPP) real-time data links or nets, as needed
Continuous interactive voice (e.g., Voice over IP telephone and radio nets)	• Multiple simultaneous MLPP voice links or nets, as needed
Continuous interactive video (e.g., Video over IP, Video Teleconferencing)	• Multiple simultaneous MLPP video links, as needed
Streaming multimedia & multicast (e.g., Video imagery)	• Multiple simultaneous MLPP multimedia links, as needed
Block transfer & transactional data Short blocks of interactive data (e.g., Telnet, HTTP, client/server, chat)	• Multiple simultaneous MLPP block & transactional links, as needed
Batch transfer data Long blocks of bulk data (e.g., Email, FTP)	• Multiple simultaneous MLPP batch data links, as needed
Operations	
Managing	Simplified network planning to include the allocation and configuration of network resources, including legacy networks, when needed

Network Capability & Attributes	Airborne Network Objective Capabilities
All aspects related to managing the links and the network including: anning -- frequency allocation, transmission, routing, network services and traffic. onitoring -- performance and use, fault, and security aspects of a link, network, or network component. halyzing -- performance optimization and diagnostics. ontrolling -- add, remove, initialize, and configure links, networks, or network components	Automated analyses of network performance to diagnose faults, determine suboptimal conditions, and identify needed configuration changes Monitoring and controlling of AN link and network resources and interfaces with legacy networks Maintenance of network situational awareness (SA) and distribution of Network SA to peer networks Match use of network resources to commander's operational objectives
Forming and Adapting To include: Provisioning -- obtaining the needed link and network resources. Initialization and Restoration -- establishing or restoring a link or network service.	• Automated provisioning, initialization and restoration of all AN link resources
Accessing All aspects related to obtaining or denying access to a link or network, to include: Protection – communications security as well as authentication, authorization, accounting Detection Reaction	• Link and subnet protection matched to the threat, with automated detection and reaction • User data and AN management and control data protection matched to the threat

2. AIRBORNE NETWORK TENETS

The following statements are tenets of the Airborne Network Architecture. These reflect the underlying principles of any AN design that claims to be conformant with the AN architecture.

1. **Standards Based**: AN system components comply with applicable DoD and AF standards lists.

- Leverage commercial investment in COTS-based networks and their evolution wherever feasible
- Relax standards only for unique must-have DoD features
- Evolve standards to accommodate DoD features
- Migrate towards use of open standards

2. **Layered**: AN system components are functionally layered.

- Follows successful COTS Internet model
- Minimizes description of inter-layer interfaces
- Allows technology evolution of layers for maximum cost benefit

3. **Modular**: AN is inherently modular in nature, capable of being extended and expanded to meet the changing communications service requirements of the platforms needed to support any particular mission.

- Components can be continuously added and removed as needed during the time frame of the mission (hours, days), such that the network can be adjusted to fit the mission, during the mission
- User capabilities that need to be supported determine the technical capabilities of the network components selected
- New network components that provide new operational capabilities can be integrated as needed.

4. **Internetworked**: AN is capable of internetworking using all available commercial and military transmission media (i.e., line-of-sight (LOS) radio communications paths, satellite communications (SATCOM) paths, and laser communications (Lasercom) paths).

5. **Interoperable**: AN is capable of interoperating with other peer networks (e.g., space, terrestrial, and warfighter networks) and legacy networks (as needed for coalition interoperability and transition operations).
6. **Implemented as a Utility**: AN integrates separate transmission mechanisms with a single common, standards-based network layer (e.g., IPv4, IPv6) for delivery of common user (i.e., mission-independent) network services.
7. **Adaptable**: AN is capable of adapting to accommodate changes in user mission, operating environment, and threat environment.
8. **Efficient**: AN efficiently utilizes available communication resources.
9. **Autonomous**: AN can operate autonomously or as part of a larger inter-network.

- Platform network can operate without connectivity to external nodes
- AN can operate without connectivity to ground nodes

10. **Secure**: AN supports user and system security.

- Multiple independent levels of security
- User, operations, management, and configuration data integrity and confidentiality
- Identification and authentication.

11. **Managed**: AN is capable of integrating into broader AF and joint network management infrastructures.
12. **Policy Based**: AN is capable of integrating into policy-based management and security infrastructures.

3. NETWORK TOPOLOGIES (NODES AND LINKS)

The Airborne Network must be capable of supporting diverse AF airborne platforms. These platforms will vary in their communications capability needs, flight patterns, and size, weight and power (SWAP) constraints. The network must be capable of interconnecting all platforms, supporting all needed services, and providing access to all needed GIG services. Some of the platforms will be high performance aircraft capable of operating at high speeds, needing to rapidly join and exit networks while having SWAP for very limited communications resources (which may be legacy systems). The network must also be capable of guaranteeing certain levels of performance to support bandwidth, latency or loss sensitive applications. Figure 2 depicts a Notional Airborne Network Topology showing the different types of network nodes and links that address these needs. To optimize network performance, operations, fault-resilience and ensure the efficient use of resources, the use of relatively stable connections should be maximized especially in the Airborne Backbone (when such a configuration is needed), while the highly mobile platforms and dynamic network connections are isolated to the Tactical Subnets. The Airborne Network should be capable of forming whatever topology is best matched to the mission, platforms, and communications transport needs as discussed in section.

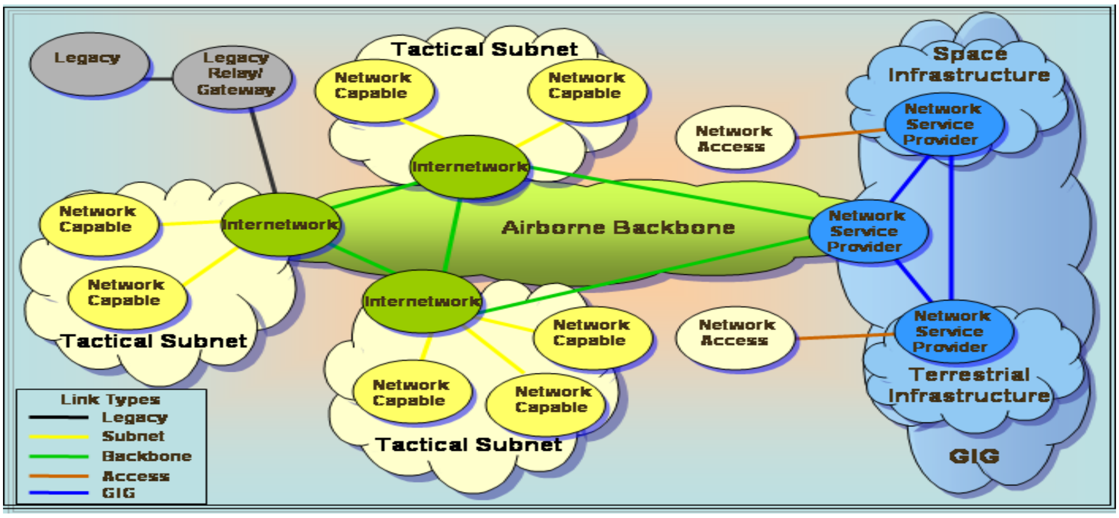

Figure 2: Notional Airborne Network Topology

3.1. Node Types:

The node types depicted in Figure 2 indicate the minimum network functionality that must be performed at each node to realize the target AN capabilities. A brief description of each node type follows:

- **Legacy** – Airborne platforms that are equipped with legacy communications systems capable of supporting voice, tactical data link (TDL), and possibly some point-to-point IP network connections for very limited services (e.g., email only).
- **Relay/Gateway** – Airborne platforms that are equipped with legacy communications systems as described for a legacy node, but also include equipment that enable them to access multiple TDLs and to relay data Beyond Line of Sight (BLOS), or transfer data formats from one link to another.
- **Network Access** – Airborne platforms equipped with IP network-capable communications systems, which provides an IP network connection to an AN or GIG network node. These nodes are tethered to the network, and do not provide any AN service to other nodes on the network.
- **Network Capable** – Airborne platforms equipped with IP network-capable communications systems, which can join an IP data network (Tactical Subnet) and provide limited AN service (e.g., transit routing) to other nodes on that local network.
- **Internetwork** – Airborne platforms equipped with IP network-capable communications systems, which can access and interconnect multiple IP data networks. These nodes are equipped with gateway and network services functionality that enable them to provide GIG services to other airborne nodes when interconnected to the GIG through a Network Service Provider node.
- **Network Service Provider** – Airborne platforms, fixed or deployed ground facilities, or space-based packages equipped with IP network capable communications systems, which can access multiple IP data networks. These nodes are equipped with gateway and network services functionality that enable them to interconnect with a GIG network (e.g., DISN, JTF Service Component Network, etc.) service delivery node (SDN) and to provide GIG services to other airborne nodes.

Table 2: Summary of Node Types and Typical Network Capabilities

Node Type	Network Capability Connectivity	Service	Operation
Legacy	• **Coverage:** Mostly LOS, some BLOS • **Diversity:** Single or few legacy links and link types • **Throughput:** Typically low speed connections • **Type of connection:** Pt-Pt, Pt-MultPt, automatic relay • **Network interfaces:** Legacy links and tactical subnets	Typically a subset of communications transport services, including: • Real-time data • Voice • Interactive data	• **Managing:** Manual planning, analyzing, monitoring, and controlling of node resources locally. Limited automated management and monitoring for some legacy links. • **Forming and Adapting:** Manual provisioning, initialization and restoration of node link resources. Limited dynamic resource sharing. • **Accessing:** Link and tactical subnet protection, with limited manual detection and reaction. Limited dynamic joining and leaving of subnets.
Relay/ Gateway	• **Coverage:** Typically LOS and BLOS • **Diversity:** Few to several legacy links and link types • **Throughput:** Typically low speed connections	Typically a subset of communications transport services, including: • Real-time data • Voice • Interactive data	• **Managing:** Manual planning, analyzing, monitoring, and controlling of node resources locally • **Forming and Adapting:** Manual provisioning,

Node Type	Network Capability		
	Connectivity	**Service**	**Operation**
	• **Type of connection:** Pt-Pt, Pt-MultPt, TDL Forwarding • **Network interfaces:** Legacy links and tactical subnets		initialization and restoration of node link resources • **Accessing:** Link and tactical subnet protection, with limited manual detection and reaction
Network Access	• **Coverage:** LOS & BLOS • **Diversity:** Single IP network-capable link • **Throughput:** Low to high speed connection • **Type of connection:** Pt-to-Pt • **Network interfaces:** Tactical subnets, AN backbone, GIG networks	All or most communications transport services, including: • Real-time data • Voice • Video • Multimedia & multicast • Interactive data • Bulk (time insensitive) data	• **Managing:** Monitoring and controlling of node resources locally and from a remote network node, distribute network SA data, match use of resources to operational objectives • **Forming and Adapting:** Automated provisioning, initialization and restoration of AN link and network resources • **Accessing:** GIG protection, with automated detection and reaction
Network Capable	• **Coverage:** Typically LOS • **Diversity:** Single IP network-capable link • **Throughput:** Low to high speed connection • **Type of connection:** Pt-Pt, Pt-MultPt, Forwarding • **Network interfaces:** Tactical subnets	Typically a subset of communications transport services, including: • Real-time data • Voice • Interactive data	• **Managing:** Monitoring and controlling of node resources locally and from a remote network node, distribute network SA data, match use of resources to operational objectives • **Forming and Adapting:** Automated provisioning, initialization and restoration of AN link and network resources • **Accessing:** Tactical subnet protection, with automated detection and reaction
Internetwork	• **Coverage:** LOS & BLOS • **Diversity:** Multiple links and link types • **Throughput:** Low to high speed connections, high speed connections to AN backbone • **Type of connection:** Pt-Pt, Pt-MultPt, Forwarding • **Network interfaces:** Tactical subnets, AN backbone	All or most communications transport services, including: • Real-time data • Voice • Video • Multimedia & multicast • Interactive data • Bulk (time insensitive) data	• **Managing:** Automated analyses of network performance, monitoring and controlling of node resources locally and from a remote network node and of connected AN resources, maintain and distribute network SA, match use of resources to operational objectives • **Forming and Adapting:** Automated provisioning, initialization and restoration of AN link and network resources • **Accessing:** Tactical subnet and AN backbone protection, with automated detection and reaction

3.2 Link Types

3.2.1 Backbone:

The AN quasi-persistent core backbone will provide a high-performance and fault-resilient routed structure that can be characterized by a defined network capacity, latency and loss rate. The backbone should be composed of relatively stable high bandwidth links between a defined set of platforms. Ideally, the backbone links should be symmetric and point-to-point with as equal bandwidth, latency, and loss characteristics as is possible. It should be implemented to enable alternative path routing and fast routing convergence, consistent steady-state traffic engineering and latency performance, and consistent failure mode behavior. This backbone should also be implemented to enable optimized paths between interconnections, dynamic load-sharing across the core structure where appropriate, and efficient and controlled use of bandwidth. [Source: Understanding Enterprise Network Design Principles]

The AN backbone will provide the following advantages to the overall network performance:

- **Reduce overall network complexity:** Even if it is based upon and formed using mobile ad-hoc networking technology, the backbone can be considered a part of the routing infrastructure that does not change nearly as frequently as other subnets attached to it. It therefore enables use of a much simpler and efficient routing protocol among backbone routers, essentially the same protocol as is used on terrestrial networks.
- **Increases overall network stability:** The fact that there are platforms whose locations and flight characteristics are relatively stable gives them the inherent ability to form relatively stable interconnections between them, whether they form these connections in an ad-hoc fashion or not. These stable links can be used in network paths between users having needs for stable and persistent connectivity.
- **Facilitates reliable performance:** Including relatively stable links in the network paths enables resources to be reserved, where needed, for traffic having high reliability requirements.
- **Provides location for common services:** Many of the nodes comprising the backbone can be used to host common network services, such as directories and gateways, so that smaller, more constrained platforms do not need to do so.
- **Provides aggregation points for SATCOM and ground interconnects:** Nodes on the backbone can serve as airborne concentration points for interconnection to the SATCOM backbone networks and terrestrial networks.

3.2.2 Subnet:

AN subnets will be formed to satisfy the specific communications transport needs of a set of platforms. The subnet links maybe point-to-point or broadcast, high or low bandwidth, LOS or SATCOM as needed to satisfy the mission needs. Subnet connections can be prearranged quasi-static connections, ad hoc quasi-static connections, ad hoc dynamic connections (connections of opportunity) consisting of any communications media capable of supporting IP traffic.

3.2.3 Network Access

AN network access links will provide connectivity to AN and/or GIG services. The network access links may be high or low bandwidth, LOS or SATCOM and function as a circuit or trunk. These links must enable AN and GIG security, addressing, network management, QoS, admission control, and network services.

3.2.4 Legacy

AN legacy links refer to any connectivity established using non-IP communications systems typically capable of supporting voice, tactical data link (TDL), and possibly some point-to-point IP network connections for very limited services (e.g., email only).

4. TYPICAL TOPOLOGIES

The Airborne Network will be capable of forming many different topologies, each matched to a particular mission, set of platforms, and communications transport needs. This flexibility will enable the AN to meet performance objectives while minimizing the infrastructure required or the use of scarce resources.

4.1 Space, Air, Ground Tether:

Tethering aircraft consists of establishing a direct connection to another aircraft or ground node, via a point-to-point link for nodes within line of sight (LOS) or via a SATCOM link for nodes that are beyond line of sight (BLOS). As in the case of the VIP/SAM aircraft that have been recently equipped with the Senior Level Communications System (SLCS) or a B-2 with reach back communications, a SATCOM link provides connectivity to a network ground entry point as shown at the left in Figure 3. Strike aircraft that accompany C2 aircraft such as an AWACS are tethered via point-to-point links as shown in the center of the figure. Finally, C2 or ISR aircraft may connect via a LOS link directly to a network ground entry point as shown at the right in the figure. Each of these tethered alternatives requires the presence of a tethering point that has been pre-positioned.

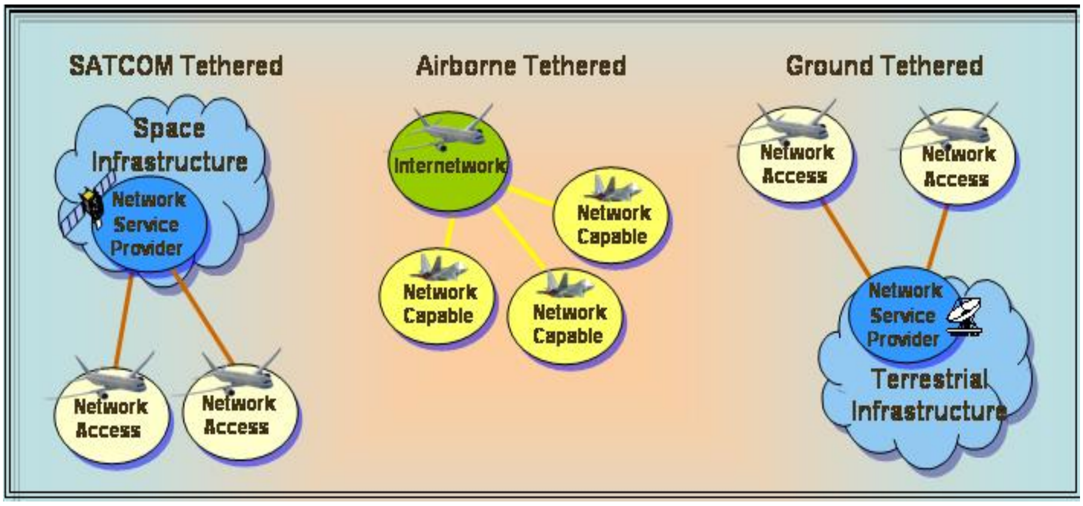

Figure 3: Airborne Network Tethered Topologies

4.2 Flat Ad-Hoc:

A flat ad-hoc topology, as shown in Figure 4, refers to establishing no persistent network connections as needed among the AN nodes that are present. With this network the AN nodes dynamically "discover" other nodes to which they can interconnect and form the network. The specific interconnections between the nodes are not planned in advance, but rather are made as opportunities arise. The nodes join and leave the network at will continually changing connections to neighbor nodes based upon their location and mobility characteristics. This type of network topology would best serve missions involving a relatively small number of aircraft that are very dynamic and have modest communications transport needs.

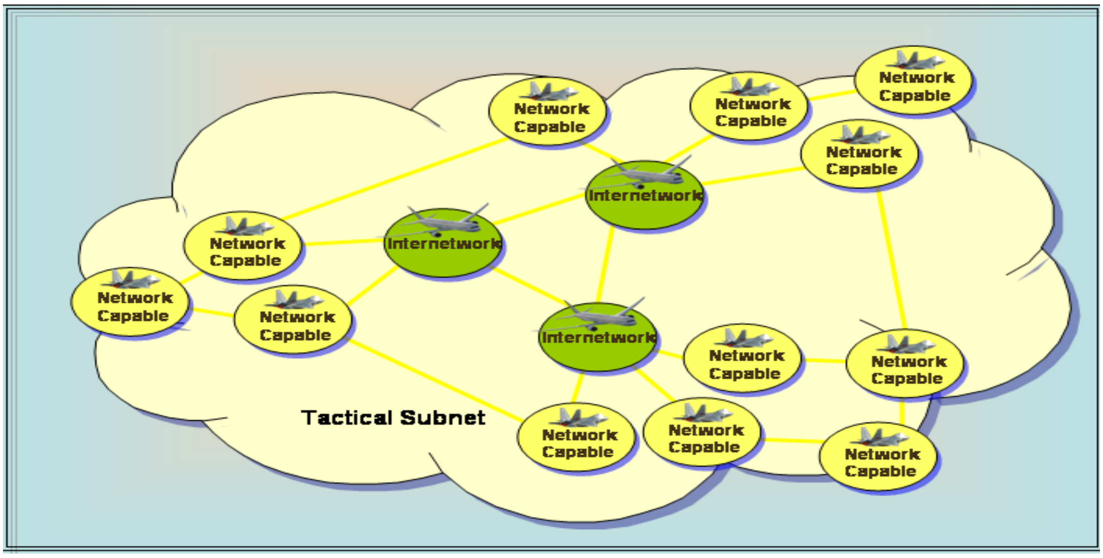

Figure 4: Airborne Network Flat Ad-Hoc Topology

4.3 Tiered Ad-Hoc:

Ad-hoc networks can be flat in the sense that all AN nodes are peers of each other in a single network, as discussed above, or they can dynamically organize themselves into hierarchical tiers such that higher tiers are used to move data between

ISSN 2348-1196 (print)
International Journal of Computer Science and Information Technology Research ISSN 2348-120X (online)
Vol. 4, Issue 2, pp: (99-113), Month: April - June 2016, Available at: www.researchpublish.com

more localized subnets. Figure 5 depicts such a tiered ad-hoc topology. This network topology would be beneficial as the number of aircraft increases, or their mobility patterns become more stable, or the communications transport needs increase.

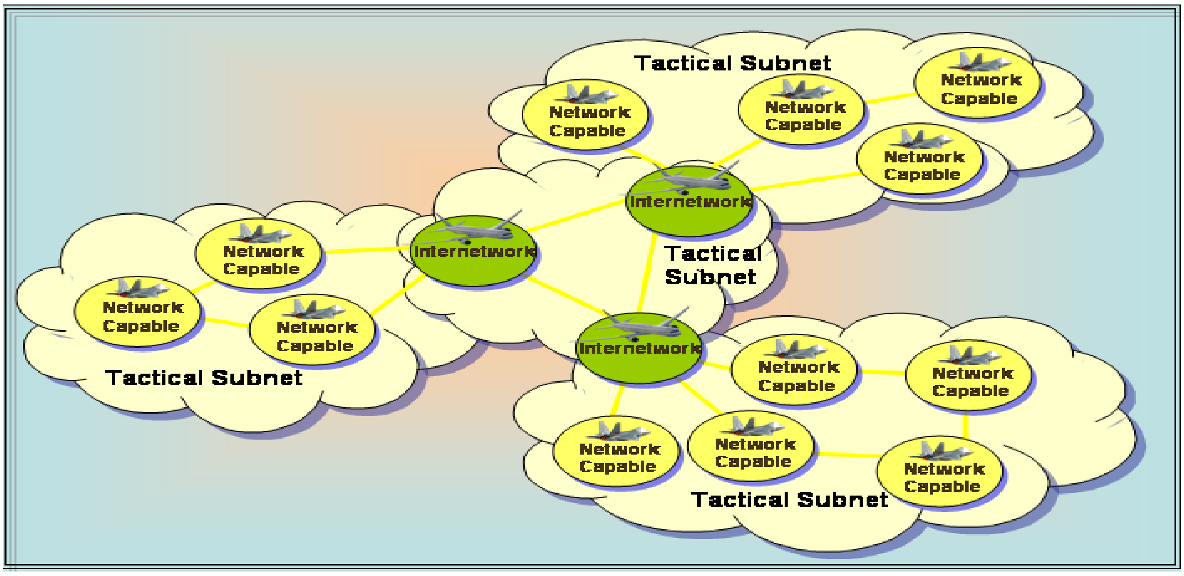

Figure 5: Airborne Network Tiered Ad-Hoc Topology

4.4 Persistent Backbone:

A network topology characterized by a persistent backbone in shown in 6. The backbone is established using relatively persistent wideband connections among high-value platforms flying relatively stable orbits. The backbone provides the connectivity between the tactical subnets which are considered edge networks relative to the backbone. The backbone provides concentration points for connectivity to the space backbone as well as to terrestrial networks. This type of network topology would be needed to support a C2 Constellation consisting of several C2 and ISR aircraft exchanging high volumes of high priority, latency-sensitive sensor and command data among themselves and with strike aircraft.

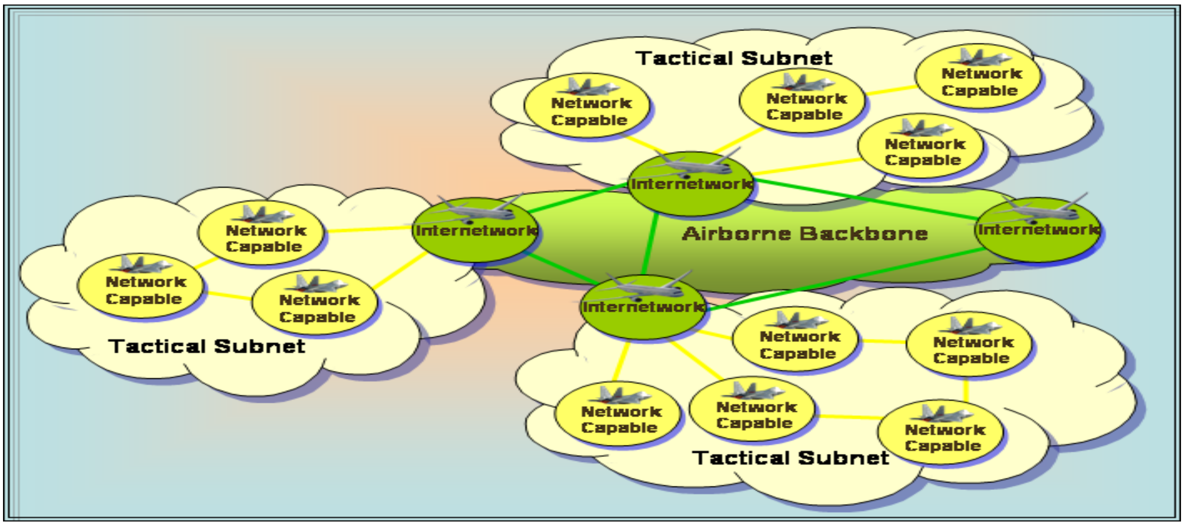

Figure 6: Airborne Network Persistent Backbone Topology

5. AIRBORNE NETWORK DESIGN AND EVALUATION CHALLENGES

To support heterogeneous network integration and autonomous end-to-end networking in ANs, many challenges need to be overcome. This section identifies two categories of challenges: design challenges and evaluation challenges. The design challenges highlight issues and complication of AN design and development due to its inherent unique characteristics.

The networking mechanisms need to be impervious to network dynamics in ANs and this poses a great challenge to protocol and service design (e.g., robust IP address assignment). Due to the highly dynamic nature of ANs, the infrastructure-based network service protocols, such as Dynamic Host Configuration Protocol (DHCP) and Domain Name System (DNS), are not readily applicable, since they are specifically designed for a stable, always connected, and error-free network environment.

(a) The network integration and auto-configuration approach should be able to operate autonomously without connectivity to external servers. In such a dynamic mobile network, autonomous and auto-configurable functionalities are needed to perform network services.

(b) The security approach needs to be capable of operating autonomously without connectivity to external servers. In such a mobile network, the mobile platform acts not only as a host, but also as a router or server for other mobile platforms. Some platforms may even act as a gateway to a subnet of platforms. Whenever AN loses its connection to the ground servers or external networks, the network security services are required to support operation in an autonomous and reconfigurable mode.

(c) ANs need to meet stringent application requirements on data delivery. A set of applications have been enabled in ANs, and these applications have high real-time and reliability requirements. In particular, a longer end-to-end delay may render surveillance information meaningless and loss of messages, e.g. due to security attacks, may affect mission critical decisions.

(d) Due to the inherent limit on interface and communication links, bandwidth efficiency is a critical factor. The communication link in ANs is capacity-constrained and subject to significant transmission delays. Any network operation (e.g., integration, and security mechanism) that is expensive, cumbersome, prone to human error, and no scalable, is typically not appropriate for large-scale ANs

(e) Airborne router should provide a capability to select the appropriate link and interface robustly. The underlying autonomous (re)configuration capability should provide seamless end-to-end communications in dynamic heterogeneous AN environments. The evaluation challenges point out requirements and limitations of existing evaluation solutions. AN technologies should be evaluated in highly dynamic and mobile wireless environments for reliable test, measurement and deployment. The following evaluation challenges can be defined.

(f) AN field tests are costly and hard to execute. Hence, there is a strong need for developing an initial testing capability that can increase the speed of AN design and reduce the cost of prototyping and deployment. The lack of realistic and cost efficient testing and performance evaluation capabilities hinders innovative technologies from being widely applied in ANs.

(g) Transmission power, modulation, coding, interference, node mobility, and channel conditions all vary over time and induce significant fluctuations in key quantities such as link capacity and delay. Performance evaluation of ANs is challenging because of the highly dynamic nature of the communication environment, including platform speed, BLOS/directional link, Doppler effects, path loss, and delay, etc.

(h) To provide realistic and practical test and performance evaluation results and to derive meaningful conclusion, AN evaluation methods should be repeatable with high fidelity such that different set of parameters can be tested over the same environment and scenarios. Also, fair comparison of different AN technologies can be achieved with trustful results and assessment.

6. HIGH FIDELITY AIRBORNE NETWORK EMULATION TESTBED

6.1 Radio Frequency Network Simulation Tool: RFnest:

To bridge the high fidelity of a hardware-based network emulator and the scalability of a software-based network emulator, Intelligent Automation, Inc., developed a wireless network emulator, RFnest, and ran a large number of tests and experiments with it. RFnest is a FPGA based network channel emulator, which allows all of the channels for a full mesh to be emulated in real time, with all communications experiencing am realistic channel impulse response and correct interference. The RFnest consists of three modular components:

- FPGA based emulation hardware with RF front ends that allows real radios to send their RF signal over an emulated channel without any modification on the radio. The FPGA will digitally modify the signals based on channel impulse response, Doppler, airframe characteristics, propagation delay, and channel (AWGN, Rayleigh, and Rician) models.

- Modeling of time-varying channel impulse response with channel properties (e.g., three-tap filter for multipath emulation and Doppler effects) based on mobility defined in a scripted or interactive GUI environment feeds computation output into the FPGA. This feature also enables feeding geographical information into channel emulation to provide a more realistic testing and evaluation environment which is very close to the actual channel condition.
- Integration with network simulators and monitoring functionality allows the user to instantiate, manage, and monitor real and virtual network nodes within the scenario. This can be achieved by using Boeing's Common Open Research Emulator (CORE) and Extendable Mobile Adhoc Network Emulator (EMANE) with additional queuing and channel switching mechanisms. RFnest is the first network emulator that allows virtual simulated nodes and real RF nodes to interact with a shared wireless feeling. This can be achieved by letting the real RF nodes receive the signals sent by the virtual simulated nodes on their real radios and vice versa through RFnest. This innovative feature enables both high fidelity and scalable network simulation and emulation with the same set of controlled and repeatable conditions.

Table 3 shows the detailed hardware specification of RFnest

RF band	2.4 GHz (Wi-Fi)
Tuning range	100 MHz
Instantaneous BW	24 MHz
Sampling	64 MHz
Sample resolution	12 bits DAC, 10bits ADC
Filter taps	3
Primary delay	<16µs for all nodes, < 500ms for one node
Number of nodes	8

6.2 Case in Airborne Network Test and Evaluation:

This section illustrates some use cases to show how RFnest is used to evaluate new architectures and protocol designs under realistic AN environments.

Robust and auto-configurable network service framework:

As ANs must be capable of self-forming and self-adapting with nodes dynamically joining or leaving the existing network, performing network services over an AN is a challenging task. Several applications require proper network service support on the airborne platforms including auto-configurable addressing, human usable naming, time synchronization, and security support. To meet such urgent needs, an Integrated robust and Auto-configurable Network Service (IANetServ) framework was developed and thoroughly evaluated with RFnest. Several mobility scenarios were developed and run multiple applications across multiple subnets through mobile nodes and airborne backbone network. The high fidelity wireless evaluation efforts were used to confirm the feasibility of IANetServ framework running on dynamic AN environments.

In this section, I briefly summarize the (a) JANSS, which defines overall features and functions for Joint Airborne Network (JAN) and (b) IANetServ framework, which enables dynamic and autonomous network service among heterogeneous airborne platforms.

(a) JANSS:

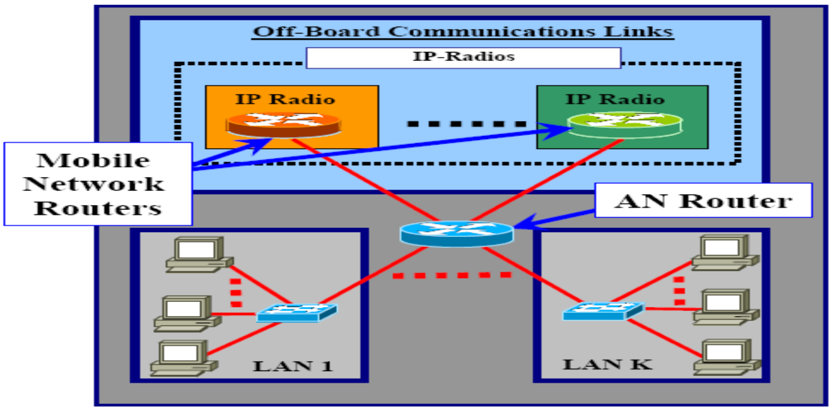

Figure 7: Airborne Network Platform in JANSS

(b) IANetServ:

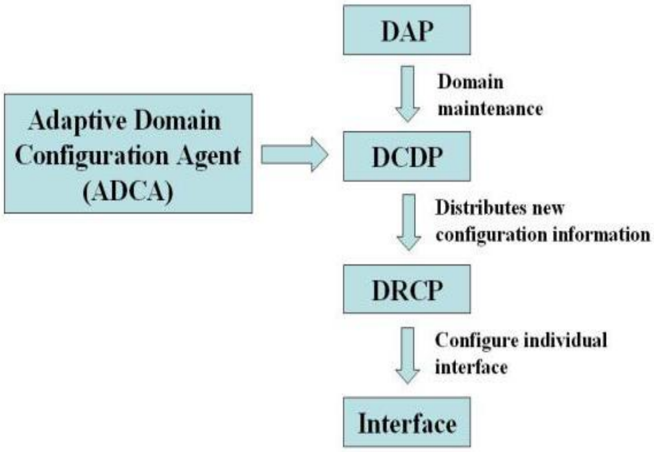

Figure 8: Address auto-configuration mechanism

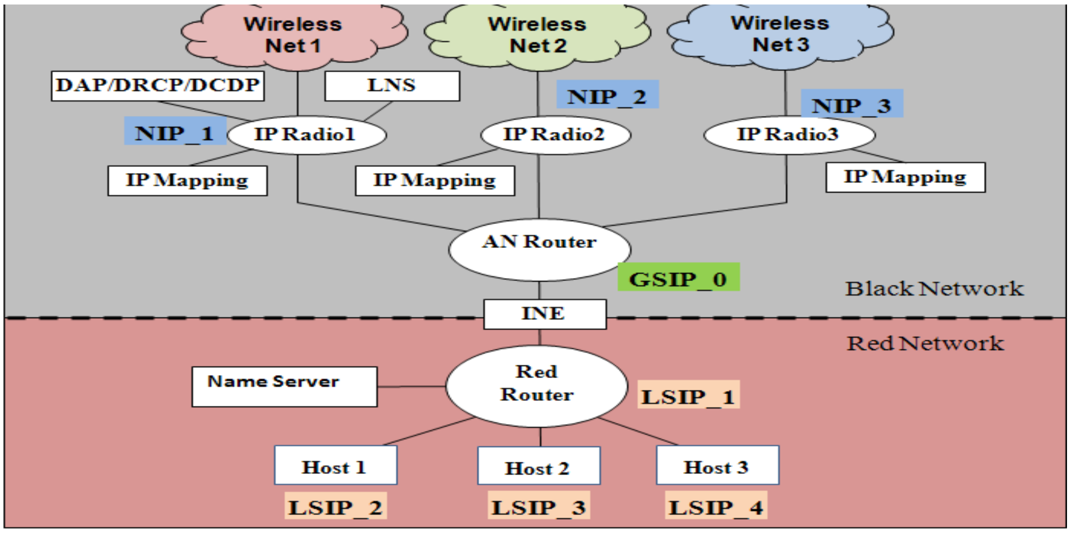

Figure 9: IANetServ framework in JANSS architecture

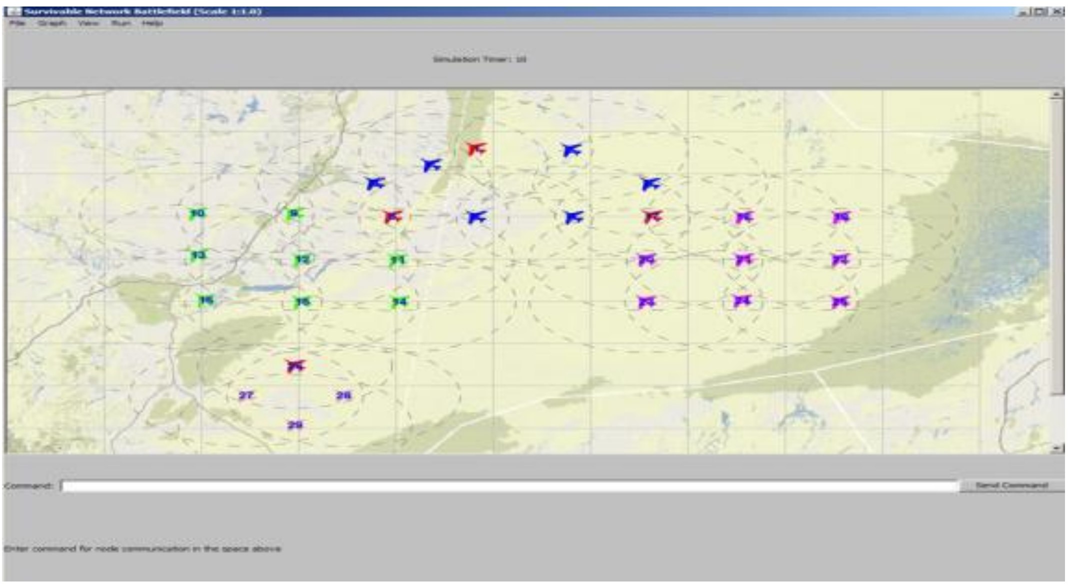

Figure 10: Initial topology

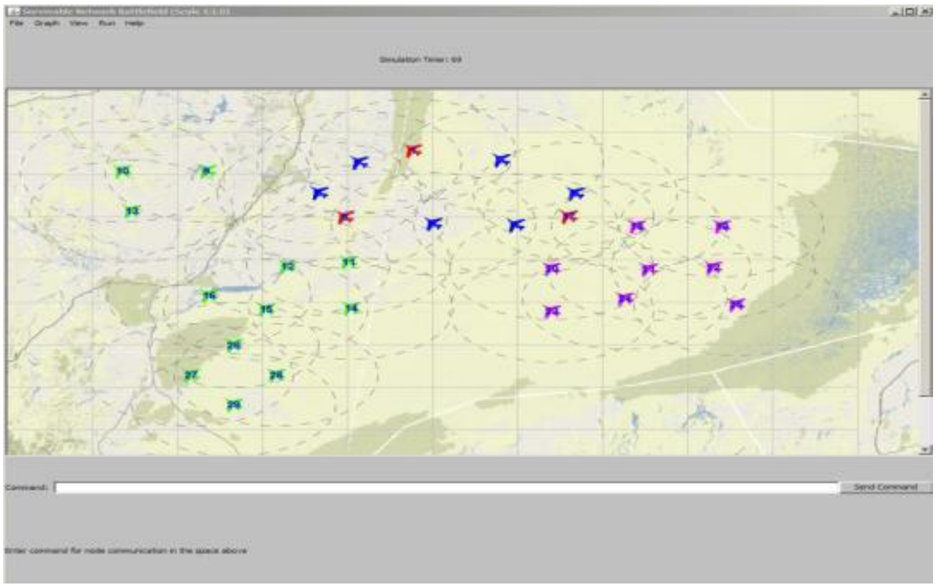

Figure 11: Two domains are merged (in color green and pink) and some nodes leave its original domain

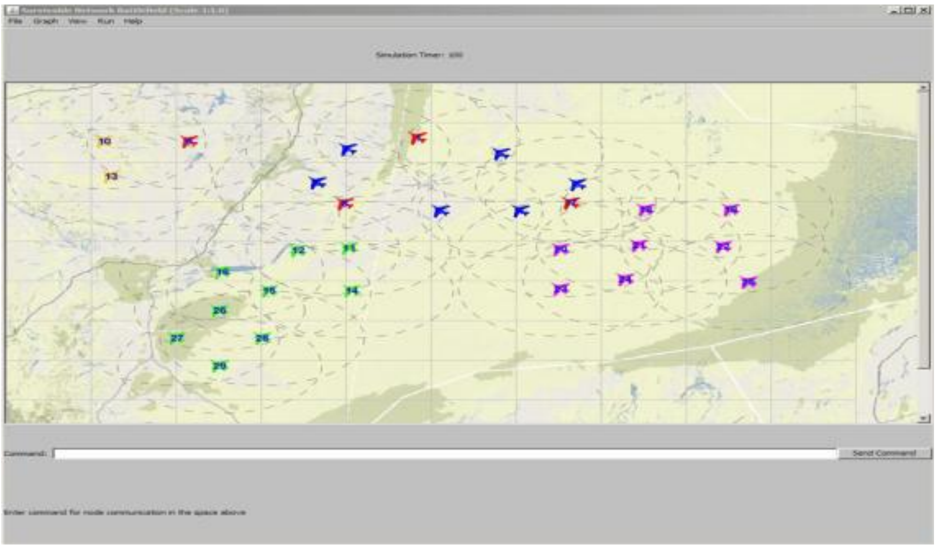

Figure 12: Isolated nodes elect a LNS server and form new domain (in color yellow)

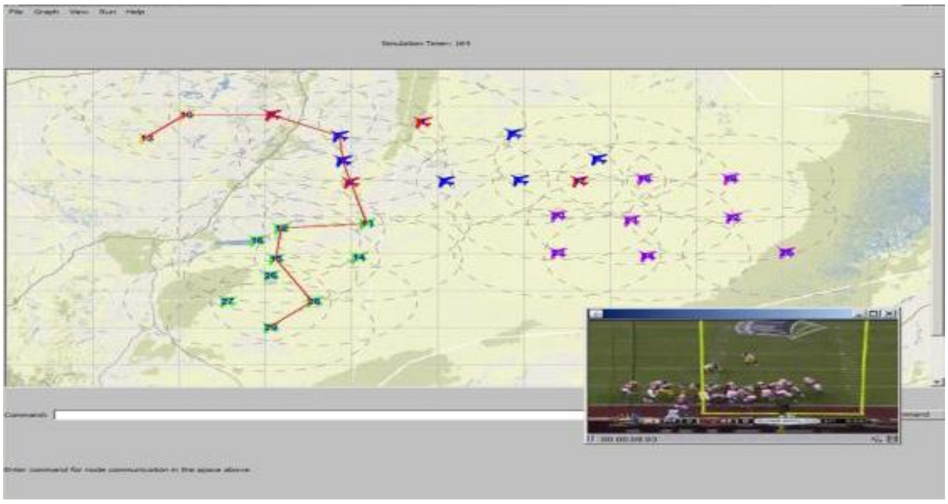

Figure 13: New domain joined the backbone network. One node transmits a video streaming to a node in the domain which just joined the backbone

7. CONCLUSION

Due to the inherent network dynamics and heterogeneous platforms/waveforms in ANs, innovative technologies and modifications are needed to guarantee reliable end-to-end connectivity. This paper identified challenges in AN design and evaluation, and introduced an efficient and realistic testing and evaluation framework. Many different AN use cases presented highlighted some innovative technologies that have been developed for ANs and illustrated how RFnest can be used for cost-efficient, scalable, and highly accurate testing and performance evaluation of new AN technologies.

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