

IEEE 802.16J-RELAY FORTIFIED AEROMACS NETWORKS; BENEFITS AND CHALLENGES

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Abstract

Aeronautical Mobile Airport Communications System (AeroMACS) is an IEEE 802.16 standard-based (WiMAX) broadband aviation transmission technology, developed to provide safety critical communications coverage for airport surface in support of fixed and mobile ground to ground applications and services. We have previously demonstrated that IEEE 802.16j-amendment-based WiMAX is most feasible for AeroMACS applications. The principal argument in favor of application of IEEE 802.16j technology is the flexible and cost effective extension of radio coverage that is afforded by relay fortified WiMAX networks, with virtually no increase in the power requirements. In this article, following introductory remarks on airport surface communications, WiMAX and AeroMACS; the IEEE 802.16j-based WiMAX technology and multihop relay systems are briefly described. The two modes of relay operation supported by IEEE 802.16j amendment; i.e., transparent (TRS) and non-transparent (NTRS) modes, are discussed in some detail. Advantages and disadvantages of using TRS and NTRS in AeroMACS networks are summarized in a table. Practical issues vis-à-vis the inclusion of relays in AeroMACS networks are addressed. It is argued that the selection of relay type may affect a number of network parameters. A discussion on specific benefits and challenges of inclusion of relays in AeroMACS networks is provided. The article concludes that in case it is desired or necessary to exclusively employ one type of relay mode for all applications throughout an AeroMACS network, the proper selection would be the non-transparent mode.

Introductory Remarks and Airport Surface Communications

The principle function of an airport surface communications system is the guidance and management of aircrafts' movement on airport surface. However, such system is also required to

support various communications needs on the part of other mobile and stationary nodes that are essential to the airport operation. This ranges from service trucks to security cameras and sensors supporting aircraft navigation. In addition, there are other procedures related to air traffic management (ATM) system that require data transmission and access to airport surface communications system. In order to support this large volume of data, wideband communication technologies were deemed required. To this end a new international standard of aeronautical mobile route services to support airport surface communications over the C-band was initiated. This band extends from 5091 to 5150 MHz, and an additional band 5000-5030 MHz may potentially become available in the future. It was recommended that this new aviation specific communication technology should be based on the IEEE 802.16e standard. The proposed system, known as Aeronautical Mobile Airport Communications System (AeroMACS) is to support fixed and mobile ground to ground and ground to air data communications applications and services [1].

The current version of IEEE 802.16 standard is IEEE 802.16-2009 (another version has been published in 2012 which is essentially the same as 2009 version) which was amended by IEEE 802.16j-2009. This amendment specifies PHY and Media Access Control (MAC) layer enhancements to IEEE 802.16e, enabling the operation of relay stations (RS) over licensed bands without requiring any modifications in subscriber stations (SS) or mobile stations (MS). In other words, the IEEE 802.16j amendment introduces multihop relay as an optional deployment enabling the extension of radio outreach and performance enhancement and/ or capacity improvement in an access network.

In all broadband cellular RS-augmented standards, the main idea is to complement the base station (BS) with less complex, less costly, and easier-to-install relay stations instead of adding new BSs to the network. The augmented BS, known as multihop relay base station (MRBS), covers an

extended area beyond what the BS alone covers which is called “multihop relay cell” (MR-cell). MRBS manages all communications resources within a MR-cell through a *centralized* or *distributed* procedure. Resource management of MS/SSs may be carried out directly by the MRBS or via radio links through relay stations. Traffic and signaling between MRBS and the SS/ MS may be routed through “*access relays*” or via a direct link between MRBS and the SS/ MS.

WiMAX

IEEE 802.16 is a large collection of protocols, therefore for any particular driven technology the scope of the standard needs be reduced to smaller sets of design choices. A case in point is Worldwide Interoperability for Microwave Access (WiMAX), which is an IEEE 802.16 standard-based broadband cellular wireless solution in which multiple access technique is OFDMA. WiMAX enables low cost mobile access to the internet and provides integrated wireless fixed and mobile services using single air interface and network architecture. WiMAX applies Scalable Orthogonal FDMA (SOFDMA) access technology for both downlink and uplink. This enhances performance against frequency selective fading effect of multipath channels and allows bandwidth scalability over several spectral ranges. WiMAX predominantly supports Time Division Duplex (TDD) architecture. TDD architecture supports the exchange of asymmetric traffic. Adaptive modulation and coding (AMC) is another key feature of WiMAX networks. With AMC WiMAX supports a variety of modulation format/ coding scheme combinations. These “*burst profiles*” are selected in an adaptive fashion depending upon channel conditions, for the objective of network throughput optimization. WiMAX networks offer multi levels of error control. Primarily, WiMAX provides error correcting coding scheme at the physical layer through AMC. Secondly a multilayer Automatic Repeat Request (ARQ) and Hybrid ARQ (HARQ) error control are included in the WiMAX

standards. WiMAX multiple access format, OFDMA, groups thousands of orthogonal subcarriers to form user’s subchannels. When neighboring WiMAX cells use the same subchannels for signal transmission “*co-channel interference*” occurs. To mitigate the effect of this interference, WiMAX applies a widely accepted method known as fractional frequency reuse (FFR). In this technique frequency reuse factor (FRF) is not a constant but rather adaptive [2, 3]. Among the many new technologies integrated into WiMAX standards is the key multiple-input multiple-output (MIMO) antenna technology. MIMO plays a central role in delivering high-speed and reliable wireless broadband services over an extended coverage area.

WiMAX Frame Structure

The frame structure, defined in the original IEEE 802.16-2009 TDD implementation, consists of downlink and uplink sub-frames, as illustrated in Figure 1. This is based on Release 1 WiMAX Forum system profile.

We note that **TDD requires system-wide synchronization to counter interference**, this is one of the down sides of using TDD; nevertheless, TDD is the preferred duplexing mode for many reasons, some of which are listed below. TDD is the duplexing mode for AeroMACS as well.

- TDD enables adjustment of the downlink/uplink ratio to efficiently support asymmetric downlink/uplink traffic, while with FDD, downlink and uplink always have fixed and generally, equal DL and UL bandwidths.
- TDD assures channel reciprocity for better support of link adaptation, MIMO and other closed loop advanced antenna technologies.
- TDD only requires a single channel for both downlink and uplink, whereas FDD requires a pair of channels.

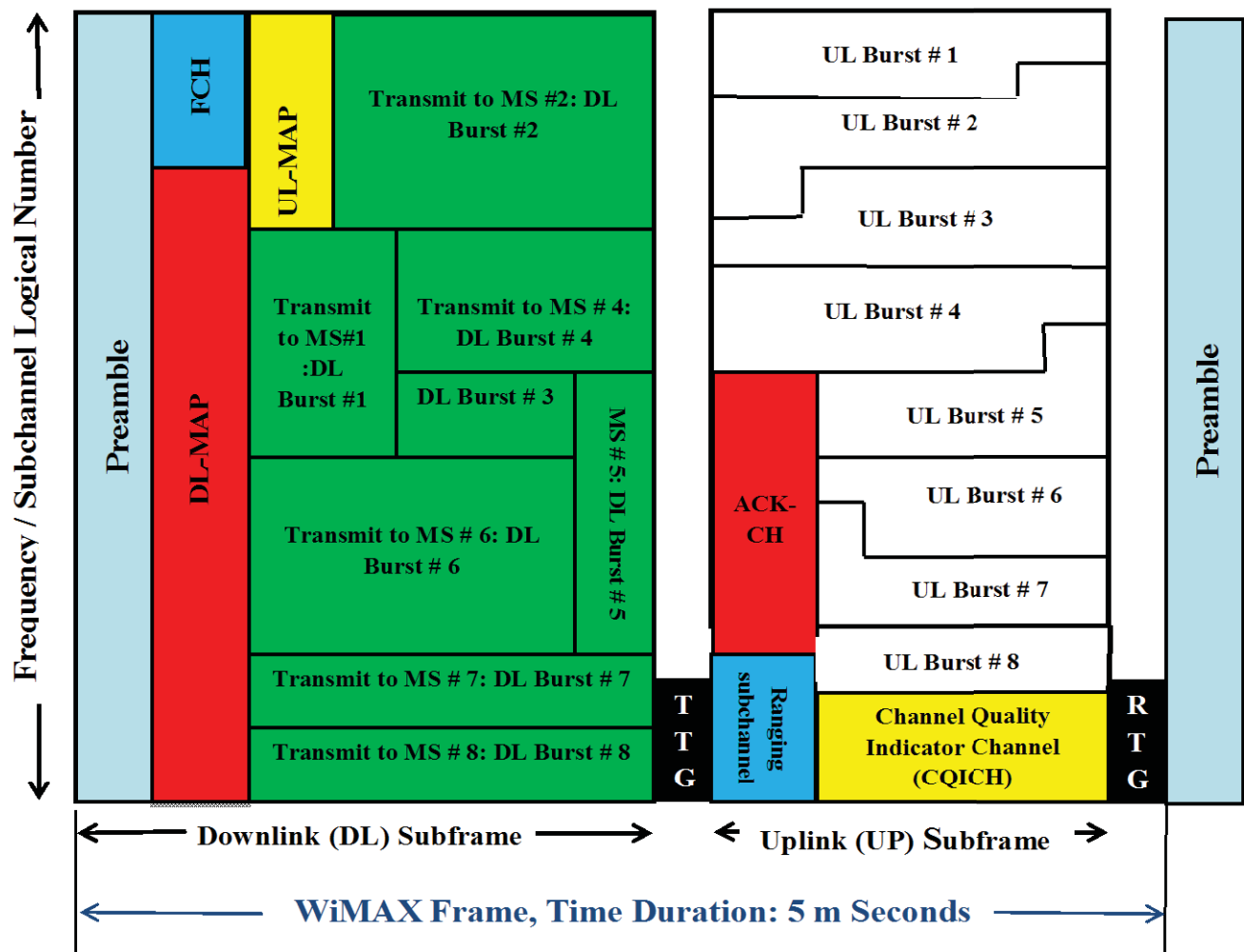


Figure1. WiMAX TDD Frame Structure

AeroMACS

The most recent version of AeroMACS System Profile is still based on WiMAX Forum Mobile System Profile Release 1, while WiMAX Forum has already published two versions of WiMAX Mobile System Profile Release 2[4].

Operational Applications

AeroMACS users groups in an airport setting vary depending upon the size of the airport. Airport authorities, airline entities, and civil aviation authorities are the major groups that need to transport application information over AeroMACS. Candidate user applications for transport over AeroMACS are

classified in 5 different “functional domain” categories.

- *Air Traffic Management/Air Traffic Control*
- *Aeronautical Information Services and Meteorological Data (AIS/MET)*
- *Aircraft Owner / Operator*
- *Airport Authority*
- *Airport Infrastructure*

Applications associated with different categories in this list may have different performance characteristics, security needs, and QoS requirements. The information content for each

application ranges from live video to low rate system monitoring data exchanges. Several applications belonging to various domain categories have been identified in the most recent AeroMACS profile document. These candidate applications include but not limited to; graphical weather data, airport sensors data, airline operations information, pilot alert system, Pre-departure clearance (PDC) and etc. [5].

AeroMACS Technical Profile

The “Future Communications Study [2]” recommended that airport surface communications system be designed based on a network centric broadband wireless technology such as IEEE 802.16 standard-based WiMAX. The incentive is to maximize the usage of COTS systems and components to keep the system cost low while minimizing additional hardware/ software development and design. The process of producing system profile for AeroMACS entails the selection of a subset of WiMAX system profile features that enable interoperability for AeroMACS. This is carried out based on a set of assumptions some of which are listed below.

1. In order to limit the AeroMACS interference into co-allocated applications, AeroMACS total radiated power will have to stay within the interference thresholds established by the ITU-R.
2. AeroMACS shall use the IP-based end-to-end WiMAX network architecture.
3. All future AeroMACS avionics and infrastructure components will be required to be backwards compatible with previously installed AeroMACS equipment.
4. AeroMACS will be designed to efficiently utilize allocated spectrum and take full advantage of the technical capabilities of the most recent version of mobile WiMAX.

Radio Profile Requirements and RF Characterization

The radio characterization of AeroMACS network is the key to the design and implementation of this network. The potential band of operation for AeroMACS will be from 5000 MHz to 5150 MHz,

although current ITU allocation is limited to the band 5091 to 5150 MHz. The following passage outlines the main radio related parameters formulated for AeroMACS [5].

1. The AeroMACS profile supports, at this point, only the 5 MHz bandwidth with the corresponding FFT size of 512 points.
2. The AeroMACS Profile Working Group (AWG) has defined preferred center frequency assignments for the spectrum 5000 to 5150 to accommodate any potential future spectrum allocations. The reference frequency is 5145 MHz, and all center frequency for radio channels are defined downward from the reference frequency in 5 MHz wide incremental frequencies.
3. Maximum Doppler velocity for AeroMACS is assumed to be 50 nautical miles per hour, although the landing and takeoff velocities of most aircrafts are well above this value.
4. All modulation formats required in the WiMAX profile, i.e. BPSK, QPSK, 16-QAM, and 64-QAM shall be required in AeroMACS. The 64-QAM modulation scheme is optional in the AeroMACS uplink.
5. The duplexing technique selected for AeroMACS is TDD.

Common Part Profile Interoperability

Referring to WiMAX profile “Common Part”, a series of tables is provided that set operational parameters for the MS the BS equipment. The AeroMACS table references for the Common Part are the same as specified in the corresponding items in the WiMAX Profile. Reference [5] provides the detail of these tables that are corresponding to the following system profile items.

1. PHY profile: refers to functionality in physical layer
2. MAC profile: refers to functionality in Medium Access Control Layer.
3. Security: refers to functionality in security sub-layer.

4. Radio profile: indicates permitted radio frequency configuration.
5. Power class profile: indicates permitted transmitted power configurations.

IEEE 802.16j Amendment and Multihop Relays

The IEEE 802.16j amendment to IEEE 802.16-2009 introduces multihop relay as an additional network entity that enables the extension of radio outreach and may be used to enhance system capacity in an access network. The amendment updates and expands IEEE 802.16 standard, specifying OFDMA physical layer and medium access control (MAC) sub-layer enhancements to IEEE 802.16 for licensed bands to enable the operation of relay stations (RS) while maintaining MS/SS specifications intact [3].

First and foremost among the benefits of employing IEEE 802.16j-defined is that relay deployment strategy presents a cost-effective, low-complexity, and easy-to-install-infrastructure alternative for wireless network radio outreach extension in a variety of situations. Secondly, the relays can provide capacity enhancement in areas which are not sufficiently covered by the associated BSs. In the majority of usage models, however, relays are deployed to satisfy a combination of the two objectives just mentioned. One other important result of deployment of the relay-fortified wireless infrastructure is the reduction of aggregate output power of the cellular network. For the AeroMACS application, this translates into less interference into co-allocated applications [6].

Transparent versus Non-Transparent Relays

Depending upon whether or not a relay station has the authority to manage network resources, or more specifically whether or not the relay can generate cell control messages, two relay modes are defined in IEEE 802.16j. They are designated as transparent relay stations (TRS) and Non-transparent relay stations (NTRS). The NTRS assigns and

manages radio resources within its own “cell”. On the other hand, TRS shares cell IDs and control messages with its MRBS. In other words, the major difference between these two modes is whether or not the relay is allowed to transmit frame header information which contains crucial scheduling data needed to determine when a node can transmit or receive information. Therefore the TRS exclusively transmits traffic data to the subordinate MS/SS, and the framing information is directly communicated from the MRBS to the MS/SSs, This implies that TRSs can only operate in centralized scheduling format and cannot be used for radio extension. The NTRSs, on the other hand transmits both traffic data and control signals to its subordinate MS/SSs, thus they may operate either in centralized or distributed mode and may be used for radio outreach extension. Table 1 compares the two fundamental modes of IEEE 802.16j-based multihop relays.

The choice of relay mode, in essence, is dictated by the application for which the relay is employed. For AeroMACS networks the major applications of relays will be radio coverage extension to severely shadowed areas and to nodes that are located far outside of airport territory, and capacity enhancement at certain location of an airport. For the first application NTRSs are required, however for the second, TRSs represent the mode of choice, although NTRSs may be also used for this purpose. Since TRSs can only operate in centralized scheduling format, they cannot support mobile relays. Moreover, they may not be used for coverage extension. The main application of the TRS is to facilitate throughput/capacity increase within a BS cell footprint. Transparent relays are of low complexity therefore they are cost efficient. NTRSs may operate in centralized or distributed scheduling schemes. The NTRS is capable of extending radio coverage which makes them suitable candidates for AeroMACS applications, where the objective is to extend radio coverage without adding a new BS and without requiring a reconfiguration of the entire AeroMACS network that is already in place.

Table 1. Advantages and Disadvantages of Using TRS and NTRS in AeroMACS Networks

Relay Mode	Advantages	Disadvantages
Transparent Relay (TRS)	<ol style="list-style-type: none"> 1. Low Complexity; needs no framing no scheduling 2. Increases throughput which may be translated to improved QoS and/ or capacity enhancement within the cell footprint 3. Can generate diversity gain 4. Ideal for cooperative communications within the framework of WiMAX 5. Straightforward handover 6. No additional overhead is needed 7. Since TRs do not transmit framing information there will be no inter relay interference 8. Ability to lower latency by using Direct Relay Zone 	<ol style="list-style-type: none"> 1. Unable to extend radio outreach 2. Cannot be implemented in multihop topology, they can only be used for the last hop in a multihop communications system 3. TR and MRBS must use the same subchannels ,that could potentially increase the interference level in the network 4. Channel quality measurement with TR is not possible 5. Mobile relays cannot be supported, as they are required to operate on distributed scheduling
Non-Transparent Relay (NTRS)	<ol style="list-style-type: none"> 1 The main virtue of this mode is capability of extending radio coverage into shadowed areas and to nodes far outside of the BS cell footprint 2 Provides flexible solution and enables several types of scheduling and RRM approaches 3 May be used for modest Increases in throughput and capacity 4 Supports multihop topology 5 Capable of operating in both centralized and distributed scheduling schemes 6 Enables straightforward cell splitting scheme 7 The NTR and MRBS can use different subchannels which can control interference 8 Mobile relays can only be supported by NTRS, for as they move they may have to be handed over to other MRBSs therefore they have to be on distributed scheduling which is solely supported by NTRS. 	<ol style="list-style-type: none"> 1. Far more complex than TRs, to the extent that they can affect the cost of the network 2. Complex RRM and frequency reuse schemes are needed when NTRs are incorporated since MRBS and all of its subordinate relays are transmitting simultaneously 3. They require guard interval that increases the overhead 4. For NTS the transmission of framing information can create high inter-relay interference, thus not much capacity improvement can be achieved with this relay mode. 5. NTR/TTR has fixed allocation for access and relay links, this a major drawback for IP networks 6. Transmission of framing information may result in high levels of interference between neighboring relays.

Quality of Service (QoS) in Relay Augmented Networks

Quality of Service in wireless networks means the probability that the network fulfills the promise of a given traffic agreement. Thus QoS manifests itself in the ability of network elements to have some level of assurance that its traffic and service requirements would be satisfied.

The key issues related to QoS are *service flow* and *bandwidth grant* provisions. A service flow is a one-way MAC service data unit (SDU) flow with a defined set of QoS parameters and an associated *service flow ID (SFID)*. A *provisioned service flow* possesses SFID but it may not carry traffic, rather it might be waiting to be activated for usage. An *admitted service flow* goes through the process of activation. An *active service flow* is an actuated service flow with all required resources allocated to it. Upon an external request for a service flow, the BS/MS will check for required resources to satisfy the requested QoS. The use of service flows is the main mechanism for providing a requested QoS [7].

WiMAX defines a set of QoS parameters which includes the key factors of *maximum tolerable latency* and *delay variation (jitter)* over the air interface connections. Combined with QoS mechanism over the backbone wireline or wireless networks (IP network), WiMAX QoS can provide predictable end-to-end QoS. When the network supports relays, the QoS analysis must also include two additional independent wireless links, i.e., MS-RS and RS-MRBS links. The multihop relay QoS is essentially an issue of assigning Service Flows (FS) individual QoS parameters for each of the wireless links.

IEEE 802.16j-Based AeroMACS; Challenges

One of the challenges of using relay-fortified WiMAX in AeroMACS is the design of QoS mechanism and the scheduler that supports it. This is due to the fact that the MS-BS and BS-MS connections may involve more than a single link. In other words relay links might be included in both uplink and downlink. These links, in general, have different channel conditions which make the

scheduling process more complicated than the conventional WiMAX network. Clearly as the number of hops increases, the scheduling process becomes more complicated.

The second problem that degrades the IEEE 802.16j-based AeroMACS is the additional latency that is created by multihop relays. The selection of the type of relay; i.e., amplify and forward (AF) relay, detect and forward (DF) relay, and demodulate and forward (D&F) relay has a direct bearing on latency. In order to determine the overall latency related to an IEEE 802.16j system the following factors need be considered.

1. The type of relay that is selected
2. The scheduling procedure
3. The maximum number of hops in the network
4. The method of dividing the resources
5. The selected relay mode.

Another issue in designing IEEE 802.16j-based WiMAX system is the number of hops. The standard does not specify the optimum number of hops, perhaps for the reason that different applications might require different optimum number of hops. The number of hops, or the maximum number of hops, is a critical parameter as it has direct bearing on latency, throughput, and QoS in the network. Clearly, as the number of hops increases, so does the latency and the time it takes for the signal to cross the channel, thus the effective system throughput decreases. Regarding the number of hops in AeroMACS networks, a key question to be answered is; should there be a maximum number of hops defined and accepted for the entire AeroMACS?

The number of hops in any WiMAX type multihop wireless network should not exceed three. The rationale is that by increasing the number of hops beyond three, the achievable user's capacity in the network dramatically decreases. Moreover, an increase in the number of hops per connection increases the latency which would affect many network parameters negatively [8].

Concluding Remarks

It has also been widely accepted that using an all-BS WiMAX network to cover a large area might be economically infeasible. Infrastructure deployment and maintenance for an all-BS WiMAX network may be too costly. It was evident that the deployment of an all-BS WiMAX system in competition with the existing 3G network may be a losing battle economically [7]. This was the key business incentive that led to the development of IEEE 802.16j amendment.

The main argument in favor of application of IEEE 802.16j technology in AeroMACS is the flexible and cost effective extension of radio coverage inside and outside of the airport real estate, that is provided by 16j networks, with virtually no increase in the power requirements and virtually no additional inter application interference. A basic IEEE 802.16j-based WiMAX cellular network can be rolled out for an airport, and as the network expands relays can be added to meet the new coverage and transmission requirements.

The following comments are in order.

- *In most cases the use of an RS can increase throughput per MS/SS which can be translated into system capacity enhancement, or QoS improvement.*
- *A single link between the BS and MS with high SINR requirement can be replaced with multiple BS to MS links, through relays, that require low SINR.*
- *Latency increases, particularly when NTRSs are employed for coverage extension.*
- *More signal overhead may be needed, the mode of relay, the number of hops will have direct effect on additional signal overhead.*
- *The MRBS will be more complex at both physical and MAC layers, and it will become more complex as the number of hops is increased.*

A BS to MS link with low SINR may be replaced with a BS to RS to MS link in which both BS to RS and RS to MS links can enjoy high SINR, particularly in C-band frequencies. Clearly the

WiMAX AMC protocols will interface these links to a modulation/ coding combination with higher level of modulation and greater coding rate, and therefore *the data rate for the MS, and as a result the overall throughput of the network will be effectively boosted and a higher spectral efficiency is achieved.* For this sort of enhancement TRS may be more appropriate.

The IEEE 802.16j standard has specified a wide variety of options. It is necessary to consider which subset of these options is the most appropriate for AeroMACS application. A new version of AeroMACS profile has been just released by RTCA [5]. This profile provides a guide for AeroMACS network design and implementation. If IEEE 802.16j-based WiMAX is to be incorporated, there are many unclear issues that need be addressed.

Finally, regarding the selection of a proper relay configuration for a given applications, the following observations are made.

- a. For radio coverage extension NTRSs are exclusively required.
- b. In order to support mobile relays, NTRSs with distributed scheduling are required.
- c. NTRSs can provide a modest throughput/ capacity improvement whereas TRS are incapable of supporting mobile relays or providing radio coverage extension.

Thus it is apparent that, in case it is desired or necessary to exclusively employ one type of relay mode for all applications throughout an AeroMACS network, the proper selection is the NTRS.

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