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## Content Based Publish / Subscribe systems for AANETs

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### ABSTRACT

AANET (Aeronautical Ad hoc NETWORKS) are a subclass of Mobile Ad-Hoc Networks (MANET). They are a very promising solution in order to answer to new air-ground communication needs. The Publish / Subscribe communication paradigm enjoys wide applicability in AANET where resources are limited. Many Publish / Subscribe systems exist for wired networks, however, these solutions are not fully adapted to mobile networks like AANET. In this article, we present the interest of a Content Based Publish / Subscribe system in a AANET. We argue that some extensions are needed to fulfill the need of aeronautical applications interested by this service. Then we present some existing solutions proposed for MANET and explain why they are not suitable for AANET. Finally, we propose a new P/S system adapted to AANET, based on an overlay built thanks to a 1-hop clustering algorithm.

### 1 INTRODUCTION

Publish/Subscribe scheme is a communication paradigm which differs in many ways from classical communication schemes where addresses are used to identify the recipients. These addresses can target a single receiver (unicast communication), multiple receivers (multicast communication) or all the users (broadcast communication). On the contrary, Publish/Subscribe systems allow *event* distribution from *publisher* (event producer) to *subscriber* (event consumer) without the use of any explicit address. Instead, the event distribution is based on declared subscribers interests. Those interests can be expressed in different ways depending on the subscription model used.

In the *topic based* subscription model, clients subscribe to topics characterized by a name. Events are then published on topics and the P/S system is in charge of the forwarding of events to clients who sub-

scribed to this topic. The topic based subscription is quite simple but it's also limited since we can only filter events from a single attribute, i.e.: the topic name.

On the other side, in the *content based* subscription model, clients base their subscriptions on the content of events. So, when an event is published, the P/S system has to forward it to the clients whose subscriptions match the event content. The filter syntax "attribute – operator – pattern" can be used to define this subscription as described in [1].

For example, persons holding stock of a company are generally interested in the evolution of its price. With a topic based P/S system, we can easily think of a solution where these clients subscribe to a 'stock topic' and receive notifications each time the price of the stock has changed. With the use of a content based P/S system, we can be much more efficient in filtering events. For example, a subscription can allow to receive notification only when price pass through a threshold.

P/S systems offer many advantages over traditional communication. In particular, they offer communications decoupled in space (subscribers do not need to know publishers and vice-versa) and potentially in time if the P/S system is able to store events for clients which are temporally disconnected (as in delay tolerant networks [2]).

In the past decade, many solutions (see for example [3] and [4]) have been proposed by the research community and industrials to build P/S system over wired networks. However, as emphasized in [5], those solutions are not adapted to the emerging category of networks called Mobile Ad hoc Networks (MANET) which are self-configuring networks of mobile nodes connected by wireless links without a fixed infrastructure. However, this paradigm should profit to AANET (Aeronautical Ad hoc NETWORKS, which consist in aircraft acting as node), which is a subclass of MANET. Indeed, in a context of increasing air traffic and new needs in term of air

ground communication systems, AANET represents a relevant solution as explained in [6] and content-based information dissemination enjoys wide applicability in this kind of networks where resources (like bandwidth) are limited. The aim of this article is to propose a new approach to build a P/S system over AANET.

This paper is organized as follow, in the next section we present possible applications of P/S systems over AANET. Then, we use those applications to explain the expected features of P/S systems in order to be adapted to an AANET context. After, we describe existing solutions of P/S systems proposed for MANET with these features and explain why they are not suitable to our purpose and constraints. Based on this analysis, the chapter 5 details our proposition to build a P/S system adapted to AANET. Finally, the last section concludes this article and introduces further work on this topic.

## 2 APPLICATION EXAMPLES IN AANET

To better understand the interest of P/S systems in an AANET context, this section introduces some examples of aeronautical applications which will be more efficient with the use of a P/S service.

### 2.1 Weather situation update

For safety reasons, weather information are crucial during a flight. Some phenomena like storm or wind shear are very dangerous for aircraft and so must be transmitted from ground weather stations or from an aircraft discovering a new situation to all aircraft that might encounter it. Today, most of these communications, in particular in oceanic area, use satellite links which are more expensive than classical air-group communication infrastructure like VDL (VHF Data Link) or HF DL (HF Data Link) network, as illustrated in [7].

A new solution for those communications can be found with the use of a P/S system over an AANET composed of commercial aircraft and ground stations. In this case, publishers would be weather stations or aircraft which have knowledge about dangerous weather situations and subscribers would be aircraft whose trajectory will get close to the concerned geographical area during the period of the weather phenomena. In order to cover this communication need, events must contain at least the following attributes: type of phenomenon, geographic area of weather phenomena and lifetime (since the weather informations are necessarily associated to a time period).

Similarly, in order to subscribe an aircraft need to know its geographical position (for example with a GPS receiver) and, if possible, its short term trajectory. Indeed, an aircraft will be only interested in weather information near its actual or short term position. A sub-

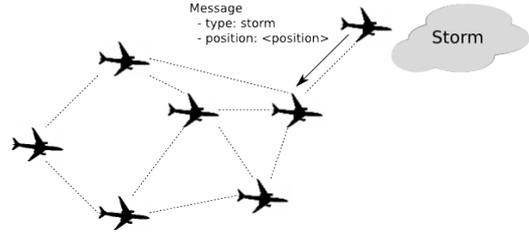


Figure 1: Example of an aircraft sending a message about a dangerous storm

scription will consequently follow the following principle : "I want to receive all weather informations regarding the geographical area <position> which will happen in the time period <time> (deduced from current position and trajectory)."

Consequently, as illustrated in figure 1, an event will be disseminated to subscribers located near the geographical area of the event, or converging to that point in the near future.

### 2.2 Message to all aircraft of an airline

Another important class of communication in civil aviation consists in the communication between airlines operational center and their aircraft (this type of communication is called Airline Operational Communication or AOC). During a flight, many information must be exchanged between these two actors (e.g.: maintenance information, crew communications, etc.). Nowadays, this kind of communication mainly uses ACARS (Aircraft Communication Addressing and Reporting System). ACARS is a network deployed in the 80s by airlines to allow data communication with their aircraft. Depending on the aircraft position, it can use VDL (VHF Data Link) network or SATCOM means. Although robust, this network has very limited resources (bandwidth in the amount of tens of Kbits/s, [8]).

As in the previous example, a new solution can be proposed with the use of a P/S system over an AANET (which offers better performance than ACARS, as explained in [6]) composed of aircraft and airline operational center. In this example, as illustrated in figure 2, publishers will be airline operational center and subscribers will be aircraft. To be properly filtered, events and subscriptions must contain at least the airline name as attribute. Furthermore, the advantage of a P/S system over a classical multicast communication would be in the filtering capabilities it offers. Indeed, more focused communications can easily be achieved with events being transmitted only to a specific type of aircraft or to aircraft bound for a given airport.

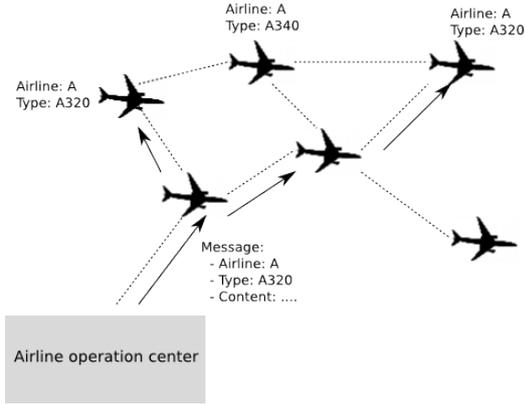


Figure 2: Example of an airline sending a message to a part of its fleet

### 2.3 Wind networking

In addition to the knowledge of dangerous phenomena, other weather information is useful for aircraft during flight. This is the case in particular of the wind which has an influence on the speed of the aircraft and hence its travel time. Now, as part of major research programs SESAR, NextGen and CARAT which aims to improve the efficiency and safety of air traffic in the world, a new concept emerged: 4D trajectory (adding the dimension time for 3-dimensional space). The main idea is to be able to use these 4D trajectories to provide air control in the near future. For a given flight, the trajectory would be negotiated between the air traffic controller and the pilot. It would become mandatory to ensure separation from other aircraft. Currently the weather data used by an aircraft in flight to calculate the time of arrival at the crossing points, and therefore the 4D trajectory are derived from forecasts provided by the weather service before departure. On long-range flights, these data can therefore be older than 12 hours, which results in significant differences between actual and forecast encountered winds and then errors in the calculation of the 4D trajectory. To solve this problem, studies are being conducted on the concept of "Wind Networking" [9].

The principle, illustrated in Figure 3, uses the fact that aircraft are capable of measuring the surrounding weather data such as wind. Based on this assumption, each flight announces its measured wind, allowing everyone to create a "real" wind map and so update the data used to calculate its 4D trajectory. In order to implement this promising concept, the use of a P/S service over an AANET seems appropriate. Indeed, each aircraft at regular intervals, sends an event with its geographical location as context and the measured wind value as content. On the other side, the aircraft subscribe to content on their short-term trajectory, the P/S system then linking the events and the interested

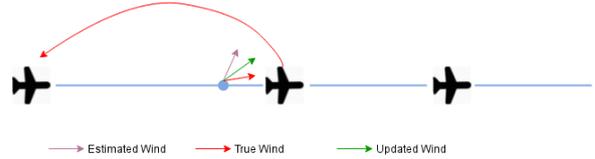


Figure 3: Principle of wind networking

aircraft.

## 3 EXPECTED FEATURES OF P/S SYSTEMS FOR AANET

The examples of the previous section show that traditional P/S system can not provide an optimal answer to the AANET content-based communication research question. In the first example, with a classical P/S solution, planes can subscribe to 'dangerous weather situation'. However, this subscription will be too large and will lead to the reception of useless events since planes are interested specifically by 'dangerous weather situation close to their position or route'. To accommodate this kind of subscription, a new concept is needed: the *node context*. Furthermore, one of the AANET characteristics is the high probability of network partitioning leading to frequent disconnections. A consequence of these disconnections is that some events (potentially critical) will not be received. To avoid this situation, a P/S system designed for AANET needs to allow *the persistence of events in the network*. These two features are detailed in this section.

### 3.1 Node context

A node context is a list of attributes which complements subscriptions, and is used to more precisely filter received events. This better filtering allows a reduction in the use of network resources which are scarce in AANET. Several definitions exist for node context. Simple definitions reduce context to the node location ("location context", see [10], [11] or [12]). Some other definitions like [13] are more generic and define the node context has a combination of static attributes and dynamic attributes, either defined in an absolute way or defined in relation with other nodes. For example, the velocity of a node can be considered as a dynamic context attribute. An absolute definition of this attribute will be 'velocity = 50 mph' while a relative definition will be 'velocity superior to the velocity of the node in front of me'. In relation to the examples discussed above, a node context would be defined as the node location, changing over time. We think that static attributes are not mandatory as they can easily be included in the subscriptions.

For the second example introduced above, the company name of an aircraft can be seen as a static context attribute. In a content-based P/S system, this context attribute could easily be replaced by an 'airline name' attribute correctly filled in subscriptions and published events.

Node context should not be mandatory to dispatch events. Indeed, in the example in section 2.2 the node location is not relevant for the communication (i.e.: an airline want to send a message to all aircraft, regardless of their position).

### 3.2 Persistent events

As explain in [14], the persistence of events is the ability for a P/S system to store events during its lifetime. Thus, subscribers interested by an event but not connected when this event has been sent are able to retrieve it later.

Traditional P/S systems for fixed infrastructure network do not necessarily implement this feature. However, this feature is essential for AANET where disconnections of node are frequent. To save network resources, the persistence can be handled with the introduction of a lifetime associated to each event. Indeed, most of the time, an event is of interest only for a given time period and can be deleted afterwards. Some solutions, like[13], also use a lifetime associated to each subscription. We do not think this is mandatory since P/S API generally include an UNSUBSCRIBE primitive to remove a subscription from the system. To add persistence to a P/S system, two family of solutions exist. Events can be retransmitted periodically by publishers, though this is costly in network bandwidth, especially for a AANET. Another solution would be to store events in the network during its lifetime. Events can be hold by publishers (the simplest way) or by any node in the network (such as a broker for a P/S system based on overlay network, see next section).

## 4 CONTEXT-AWARE P/S SOLUTIONS IN MANET

Some P/S systems, with the specific features introduced in the previous section have been proposed for MANET or VANET (Vehicular Ad Hoc Network, a subcategory of MANET whose nodes are vehicles). They can be classified in three categories: geographic routing, proximity routing and overlay network based solutions.

### 4.1 Geographic routing based solutions

Geographic routing based solutions like [15] or [13] are based on the assumption that each event / subscription is linked to a geographical area. The publish /

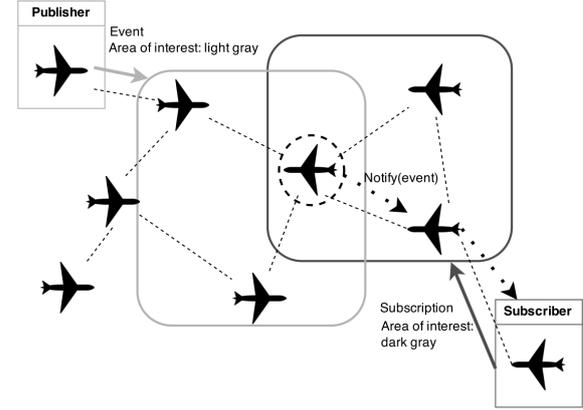


Figure 4: principle of geographic routing based P/S

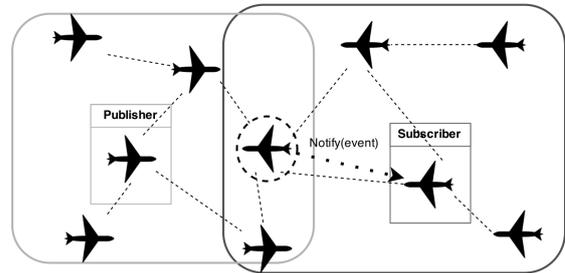


Figure 5: principle of proximity routing based P/S

subscribe system uses a geographic routing protocol to dispatch events from the publisher to the subscribers. Actually, an event is sent to the nodes located in the geographical area defined as the context of the event. In the same way, a subscription is sent to the geographical area defined in the context. Then, as described in figure 4, when a subscription matches with an event, nodes located at the intersection can act as middleman between publisher and subscribers.

### 4.2 Proximity routing based solutions

Proximity routing based solutions like [11] or [16] provide many likeness with the previous solution. The main difference relates to the area where events and subscriptions are sent. This kind of solutions disseminate events/subscriptions only within a radius close to the sender (see figure 5).

### 4.3 Overlay based solutions

Overlay network based solutions introduce a new component in P/S architecture, *the broker*. Brokers are responsible for dispatching events from publishers to subscribers. They are interconnected and thus form an overlay network. In most of these solutions, like [17], brokers form an acyclic graph. Subscriptions are

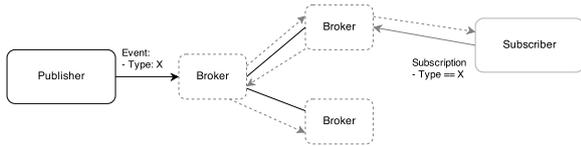


Figure 6: principle of overlay network based P/S

thus sent to all brokers of the graph (or just a part of it if context is used to filter recipient brokers). Based on these subscriptions, they can populate the table used to forward events to interested subscribers.

#### 4.4 Performances in AANET context

In order to assess the relevance of the solutions introduced in the previous paragraphs, some performance evaluations have been conducted using simulation models developed on Omnet++ software. The mobility model used for the simulations is based on real traffic traces from the French civil aviation authority and Eurocontrol based on either radar data or position report from the aircraft itself. As AANET is especially interesting for area where no ground infrastructures are available, as over oceans, we choose to reduce the scope of our simulations to the transatlantic traffic. That is why our simulations take into account aircraft whose latitude belongs to the interval  $[23,5^\circ - 70^\circ]$  and the longitude belongs to the interval  $[-90^\circ - 10^\circ]$ .

Two applications has been modeled for this evaluation : the announce of dangerous weather phenomenon and the communications from an airline to its fleet. Three P/S systems has been compared during these tests :

- The first one is a simple heuristic which is sending events to all nodes of the network. This solution is used as reference since, intuitively, we know that it will offer best performance in terms of delivery ratio of events even if the use of the network capacity will not be optimal ;
- The second one is a geographic routing based solution. LBM (Location Based Multicast) [18] is the geographical routing protocol used to dispatch events and subscriptions. LBM allows to send a packet to all nodes within a target geographic area (called a multicast region). In this way, the sender of the message defines a forwarding area according to his position and the multicast region. Only nodes within the forwarding area retransmit the message. This family of Publish / Subscribe solutions also requires a unicast protocol in order to send an event from the node used as an intermediary to subscribers interested by the event. In our case, we choose AODV [19] (Ad hoc On-Demand

P/S System	Simple	Geographic	Proximity
Delivery ratio	$63.17 \pm 0.2\%$	$59.9 \pm 0.4\%$	$50.7 \pm 0.2\%$
Network load (in Gbits)	$23.3 \pm 0.57$	$59.8 \pm 6.4$	$19 \pm 0.26$

Table 1: Performance of P/S systems

Distance Vector). This choice was motivated by the nature of the network (hundreds of highly mobile nodes) and the quality of service expected by the application.

- The third one is a proximity routing based solution. For each event/subscription, a proximity perimeter is defined (parameter of the simulation). The message is sent to all nodes in this area. As with previous solution, when a node receives an event from which it knows subscribers, AODV is used to send this event to recipients.

The table 1 shows the results obtained with the traffic of the December 12 2012. For each P/S system, two results have been observed. The first one is the *Delivery ratio*. for each event

$$Ratio = \frac{\text{Number of subscribers that received the event}}{\text{Total number of subscribers}}$$

The second one is the *Network load*, which is the total number of bytes sent in the network (including control message) to dispatch events to subscribers. It is calculated as the sum of sent bytes (at the level of MAC layer) for all nodes of the network.

These results show that interesting approaches for MANET or VANET like the use of geographical routing protocol or proximity based approach are not suitable in this situation and lead to worse results than a basic approach based on the broadcast of the event in the network. However, we have to keep in mind that this approach is a very bandwidth consuming solution and can not be deploy in an AANET.

## 5 A NEW P/S SYSTEM ADAPTED TO AANET

Since the evaluated solutions in the previous section are not totally efficient in a AANET context, our proposition is to build a P/S system over a hierarchical structure such as a clustered structure. This proposition is detailed in this section.

### 5.1 Clustering algorithm

The aim of a clustering algorithm is to organize the mobile nodes in a number of virtual groups called clusters. In a group there are usually three types of nodes as shown in figure 7.

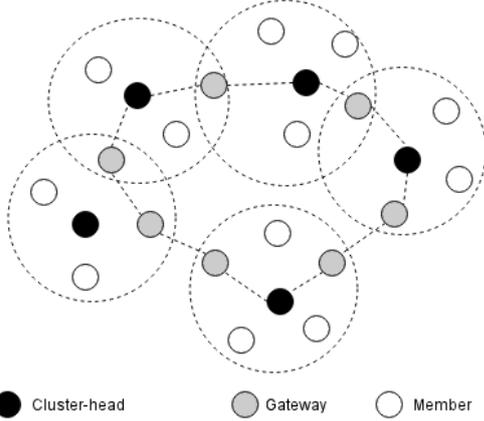


Figure 7: Roles in a cluster

- The cluster-head in charge for the management of the group. There is only one cluster-head per group.
- The gateways which are able to communicate with nodes located in neighbor groups.
- The other nodes are simply member of the group.

In MANET, the clustering algorithms have been developed mainly to improve the efficiency of dynamic routing by building a hierarchical structure. Indeed, the existence of a hierarchical architecture allows to differentiate the behavior of the protocol between intergroup and intragroup communications. In our proposition, regarding this idea, we adapt it to build a scalable P/S system for AANET.

## 5.2 Working principle of P/S system

The main idea of this P/S system is to use cluster-heads as *brokers*. They have two main functions. The first one is to collect events and subscriptions of cluster members. The second one is to dispatch events in the group if at least one member is interested by the content of this event.

The other choice, done for the development of this system, is to use unicast and multicast routing service offered by the network layer (IP layer in our case). For example, when a cluster-head wants to send a message to all other cluster-heads, this message is encapsulated in an IP packet whose destination address is a multicast address on which all cluster-heads are subscribed. Precisely, an approach proposed in this P/S system is to transmit events to all the groups available in the network. The working principle is then:

- All cluster members send their subscriptions to their cluster-head. It saves them in a table containing the identity of the source, the identifier

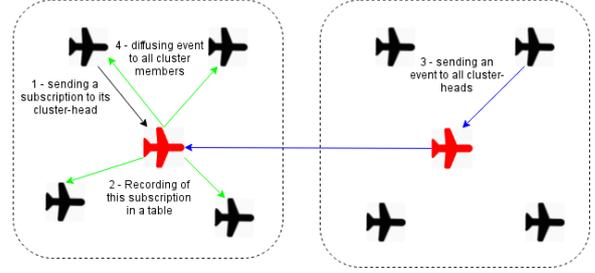


Figure 8: Principle of overlay network based P/S

Results	Delivery ratio	Network load (in Gbits)
Simple heuristic	$77.6 \pm 1.4\%$	$12.3 \pm 0.11$
Geographic	$69.5 \pm 0.4\%$	$32.4 \pm 2.2$
Proximity	$54.6 \pm 2.3\%$	$4.73 \pm 0.21$
<b>Cluster based</b>	$73.7 \pm 1.0\%$	$2.0 \pm 0.11$

Table 2: Performance of our cluster based P/S systems regarding the other solutions

(unique in all the network) and constraints related to this subscription.

- When an event is generated, it is transmitted to all cluster-heads, using the multicast routing service.
- For each received event, cluster-heads consult their subscriptions table and if one of them matches, this event is dispatch in the cluster.

This principle is illustrated with the figure 8.

## 5.3 Performance evaluations

In order to evaluate the efficiency of our P/S system, we compare it with the solutions introduced in section 4. The results are detailed in the table 2. For these simulations, we use the traffic of the June 28 2013.

These results confirm the relevance of our approach. Indeed, the delivery ratio obtained with our proposition is close to the one obtained with the simple heuristic. Furthermore, the network load is considerably lower than all the other solutions (around six times lower than the simple approach for example).

## 6 CONCLUSION

In this article, we introduced a proposition for content based P/S system adapted to AANET. We first presented the concept of P/S system. Then, to highlight the interest of this paradigm in an AANET, we detailed three examples of aeronautical application which will be more efficient with the use of a P/S service. Using these applications, we have extracted two mandatory features of P/S systems for AANET, namely the node context filtering and the persistence of events in

the network. Since some solutions with these features have already been proposed for MANET or VANET, a brief state of the art is presented in this article. The existing solutions can be classified in three categories: geographic routing, proximity routing and overlay network based solutions. However, using a simulation approach, we demonstrated that these solutions are not fully adapted to AANET. That's why we proposed a new P/S system suitable to AANET. This solution uses a hierarchical structure, built thanks to a clustering algorithm, to dispatch events to interested subscribers. Further work will concentrate on the optimization of our solution and the enhancement of our simulation model.

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